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Francesco Canestrari
Manfred N. Partl *Editors*

8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials

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RILEM BOOKSERIES

Volume 11

RILEM, The International Union of Laboratories and Experts in Construction Materials, Systems and Structures, founded in 1947, is a non-governmental scientific association whose goal is to contribute to progress in the construction sciences, techniques and industries, essentially by means of the communication it fosters between research and practice. RILEM's focus is on construction materials and their use in building and civil engineering structures, covering all phases of the building process from manufacture to use and recycling of materials. More information on RILEM and its previous publications can be found on www.RILEM.net.

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Editors

8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials

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Preface

RILEM (*International Union of Laboratories and Experts in Construction Materials, Systems and Structures*) is a volunteer organization grouping academics, researchers, testing laboratories, suppliers, and contractors with the aim to promote scientific cooperation in the area of construction materials and structures.

In the field of bituminous materials, since late 1960s, RILEM activities are organized through Technical Committees (TC) that delivered outstanding products such as guides to good practice, recommendations and prestandards, proceedings of symposia and workshops, state-of-the-art reports with extensive data basis, and papers in international journals.

The *8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials* belongs to a series of RILEM Symposia started in 1968 (Dresden) and follows up the last organized in Rhodes six years ago.

Nowadays, the increasing mobility demand and traffic loads call for using innovative high-performance materials and techniques for asphalt pavements and, at the same time, for taking care of environmental concerns in search of more sustainable infrastructures.

For the above-mentioned reasons, the main goal of the symposium is to enhance knowledge on sustainable and innovative bituminous materials as basis for their appropriate and reliable application within the pavement network. Achieving such objectives requires developing and implementing performance-oriented test methods through promotion of international networking and synergies.

In accordance with these objectives, over 80 papers from 26 countries were accepted after a rigorous peer review addressing the following topics:

- Characterization of binder–aggregate interaction;
- Innovative testing of bituminous binders, additives, and modifiers;
- Durability and aging of asphalt pavements;
- Mixture design and compaction analysis;
- Advanced characterization of interlayer systems;
- Modeling of road materials and pavement performance prediction;

- Environmentally sustainable materials and technologies;
- Advances in laboratory characterization of bituminous materials;
- Field measurement and in situ characterization;
- Recycling and reuse in road pavements;
- Cracking and damage characterization of asphalt pavements.

As it can be seen, the content of these proceedings appeals not only to researchers and students at university level but also to practitioners and decision makers providing an update on latest environment-related developments and performance-based evaluations in the field of testing and characterization of sustainable and innovative bituminous pavement materials and technologies.

We trust that the rigorous experimental approach and theoretical background adopted by the authors of the accepted papers will contribute to a further leap toward sustainable applications of bituminous road materials.

Moreover, we hope that the pavement engineering research community will understand this symposium as an opportunity to strengthen its efforts in fostering the environmentally friendly use of asphalt products for the sake of future generations.

For this reason, the editors would like to thank the RILEM Steering Committee of this symposium for supporting the main strategic decisions and all authors and reviewers for contributing to the excellent quality of the accepted papers. Their effort is highly appreciated.

Finally, we would also like to acknowledge the invaluable contributions from the Local Organizing Committee with its enthusiastic members, who have tirelessly dedicated time to the success of the symposium.

Ancona
October 2015

Francesco Canestrari
Manfred N. Partl

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Part I
Characterization of Binder-Aggregate Interaction

Development of Failure Master Curve for Asphalt Mastics Characterization

Pouya Teymourpour and Hussain U. Bahia

Abstract Low temperature performance grading currently relies solely on Bending Beam Rheometer (BBR) for determining low temperature creep stiffness (S) and rate of modulus relaxation (m-value) at 60 s, both determined at low stress-strain levels, in the pre-failure zones. This aspect raises questions with regard to applicability of properties derived from the linear viscoelastic range for prediction of asphalt binder thermal cracking behavior. Furthermore, many researchers have reported a discrepancy between field cracking severity and predictions based on asphalt binder properties since the asphalt binder-aggregate interaction is non-existent in asphalt binder testing. Therefore evaluation of asphalt mastics properties which could save a considerable amount of time and equipment in comparison to mixture testing should be prioritized. These challenges indicate that considering fracture properties of asphalt mastics could be a better approach for prediction of thermal cracking in asphalt pavements. It is believed that development of failure master curves for the damage characterization of asphalt mastics at different temperatures and loading rates would be beneficial for better characterization of resistance to thermal cracking. Therefore, this study presents framework and preliminary results on the development of such asphalt mastic failure master curves using the new BBR-SENB test for damage resistance characterization. The complexity of the visco-elastic behavior of asphalt mastics in terms of time and temperature dependency is also recognized by the sensitivity of the failure properties to changes in loading time and temperature.

Keywords Asphalt mastic failure master curves · Strain at failure · Single edge notch-bending (SENB) · Rheology · Visco-elastic behaviour

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1 Introduction and Background

Since early 1900s the importance of the material selection for performance of asphalt mixtures has been realized and studied. Superpave, as the final product of the SHRP asphalt program is a performance related asphalt binder and mixture specification currently used in North America. Current Superpave asphalt binder specifications are based on linear viscoelastic properties and were primarily developed for unmodified asphalt binders. However, research has demonstrated the importance of damage resistance characterization of asphalt binders with respect to pavement distresses (Bahia et al. 2001). Given the increased complexity of mixes currently being produced, including WMA, mixes with high recycled components content, etc. and the fact that mixes accepted under the current specification framework exhibit varying levels of distress while in-service, it is essentially important to incorporate the damage characterization of asphalt materials.

Low temperature cracking is one of the major distresses in asphalt pavement which is a source of pavement deterioration and structural failure. Thermal cracks in asphalt pavement form as a result of high cooling rates and/or low pavement temperature drops due to climatic events. Asphalt research community has investigated thermal cracking extensively in the past two decades and yet it remains one of the most challenging pavement distresses to be evaluated and predicted. Significant progresses have been made in understanding the mechanisms and factors affecting this distress. However current low temperature specification relies on the rheological performance indicators as well as the time-temperature superposition principles under linear viscoelastic small stress-strain conditions. Low temperature performance grading currently relies solely on Bending Beam Rheometer (BBR) for determining low temperature creep stiffness (S) and rate of modulus relaxation (m-value) at 60 s, both determined at low stress-strain levels, in the pre-failure zones. This aspect raises questions with regard to applicability of properties derived from the linear viscoelastic range for prediction of asphalt binder failure properties, especially for modified asphalt binders.

Polymers and polymer-based composite materials usually exhibit time-dependent behavior. Relationship between time and temperature has been significantly important in investigating these types of materials. The time-temperature superposition is one of the most efficient methods for predicting the long-term behavior of polymers. This principle in which time is equivalent to temperature for viscoelastic materials was first proposed by Lenderman in 1943 (Starkova and Aniskevich 2009; Cheng and Yang 2005). Williams, Landel and Ferry subsequently proposed a semi empirical formula based on the concept of free volume to describe the principle quantitatively known as Williams-Landel-Ferry equation (Williams et al. 1955; Cheng and Yang 2005). The TTS principle has also been shown that can be applicable to asphalt materials and these types of materials can have thermo-rheologically simple behavior in small strain deformations. This implies that properties of the material at different set of conditions can be predicted by a limited set of stress-strain measurements under a given set of temperature and loading rates/frequencies (Andriescu and Hesp 2009). Theoretical 'master curves' were then developed in order to express the effect of time and temperature on viscoelastic properties of material considering the effect of each factor to be equivalent. Master curves are determined by transiting the graphs of the viscoelastic functions (determined at different temperatures) along the log time or frequency axis at one reference temperature until they form a continuous curve. Christensen and Anderson have shown that the temperature dependence of asphalt binder can be expressed using the WLF equation and the shift factors determined from rheological data may be used to generate failure master curves (Anderson et al. 1994).

During the development of the Strategic Highway Research Program (SHRP) the time-temperature superposition principle was used to develop the low temperature specification of asphalt binders (Anderson et al. 1994; Anderson and Kennedy 1993). Significant progress has been made in understanding the rheology of bitumen under small stress-strain conditions. Traditionally, master curves for rheological properties such as complex modulus (G*) and phase angle (δ) have been used to predict the response of bitumen under different loading time and temperature conditions. Time-temperature superposition combines the rheological property data obtained at different temperatures to generate the master curves by shifting the data obtained at different temperatures horizontally with respect to time until they merge into a single smooth curve (Anderson and Kennedy 1993). This has to be done in order to effectively model the behavior of asphalt binders and predicts the stress-strain relationships over a wide range of temperatures and loading times.

The linear viscoelastic behavior of the asphalt binders determined from rheological master curves can be a good tool to predict the low temperature behavior of asphalt binders. Recently there have been some efforts in verifying the application of TTS during the presence of cracks in asphalt materials. In one of these studies the validity of TTS was evaluated when cracks initiated and propagated in asphalt mixtures using the four point bending beam. They have reported that by applying same shift factors driven from complex modulus of asphalt mixture, the smooth master curve can be captured crack propagation in asphalt mixtures (Nguyen et al. 2013). However, little work has been reported on the development of failure master curves for the non-linear and damage characterization of asphalt binder and asphalt mastics for different temperatures and loading rates, which might be necessary for the specification purposes and for a more realistic materials characterization. This study presents preliminary results on the development of such failure master curves for both asphalt binder and asphalt mastics. Failure characterization of bitumen and mastics is performed by using the Single Edge Notched Bending (BBR-SENB) test at different loading rates and testing temperatures. Stress and strain at failure (σ_f and ε_f) are used as the properties to be shifted in the generation of the failure master curves.

The main objectives of this study are to determine the effects of asphalt binder-mineral filler interaction on thermal cracking behavior of asphalt mixtures through developing asphalt mastic failure master curves and cover shortcomings in the knowledge of asphalt mastics brittle and ductile fracture behavior.