RILEM State-of-the-Art Reports

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Hervé Di Benedetto · Herald Piber
Dariusz Sybilski *Editors*

Advances in Interlaboratory Testing and Evaluation of Bituminous Materials

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RILEM STATE-OF-THE-ART REPORTS
Volume IX

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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It is RILEM's hope that this information will be of wide use to the scientific community.

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Advances in Interlaboratory Testing and Evaluation of Bituminous Materials

State-of-the-Art Report of the RILEM Technical Committee 206-ATB

Springer

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Preface

Bituminous materials and pavement technology currently undergo a dynamic innovative transition from a traditional empirical to a mechanistic way of engineering along with a change from phenomenological materials technology to materials science. This challenging transition process has been triggered by different factors, such as increasing performance requirements in terms of durability and bearing capacity, decreasing public tolerance to obstructions from repair and maintenance, tighter construction conditions through time and cost pressure as well as increasing environmental requirements for materials and construction. It is also driven by the understanding that asphalt roads can play an important role for future sustainable development, for example, by noise reduction, saving of material resources through recycling or use of marginal materials, and by saving energy during construction and production.

After gaining momentum by the end of the last century, this development has produced a great variety of new bituminous road materials and construction technologies worldwide which, as painfully learned by costly failures, can often not be handled sufficiently by traditional empirical materials engineering and testing, but are clearly asking for advanced test methods and improved understanding of mechanical behavior in a fundamental engineering and scientific way.

The *International Union for Testing and Research Laboratories for Materials and Structures* (RILEM) has therefore created over the years different Technical Committees working on specific material related questions regarding characterization and performance testing of bituminous binders, mixtures and pavement structures.

One of these Technical Committees was RILEM TC 206-ATB, on "Advanced Testing and Characterization of Bituminous Materials" which has been active between 2004 and 2010. It concentrated on simple and universally applicable performance based and physically sound fundamental test methods as well as homogeneous and uniform specimen preparation procedures for an ever increasing variety of bituminous binders and mixtures.

The RILEM TC 206-ATB (Chair: Manfred N. Partl, EMPA, Switzerland; Secretary: Emmanuel Chailleux, LCPC/*now IFSTTAR*/, France) was composed of five Task Groups:

- *TG 1 Binders* (Convener: Dariusz Sybilski, IBDIM Poland)
  Evaluation of binder properties with respect to durability relevant distress accumulation, performance and application
- *TG 2 Mixture design and compaction* (Convener: Hussain U. Bahia, Univ. Wisconsin-Madison, USA)
  Evaluation of laboratory compaction methods and models with respect to field compaction
- *TG 3 Mechanical testing of mixtures* (Convener: Hervé Di Benedetto, ENTPE, France)
  Evaluation of existing test methods and models for different types of mixtures considering topics such as permanent deformation, micromechanics and size effects
- *TG 4 Pavement performance prediction evaluation* (Convener: Herald Piber, Bautechnik Carinthia, Austria, followed by Francesco Canestrari, Univ. Politecnica delle Marche, Italy)
  Evaluation of test methods to assess structural behavior such as interlayer bond and investigation of sections for pavement performance prediction evaluation (PPPE)
- *TG 5 Recycling* (Convener: Chantal de la Roche, LCPC/*now IFSTTAR*/, France)
  Evaluation of test and mix design methods for the use of materials with bituminous materials reclaimed from asphalt pavements, focusing on hot mix recycling.

This book presents the achievements of RILEM Technical Committee TC 206-ATB on “Advanced Testing and Characterization of Bituminous Materials” which were gathered over several years by intensive international interlaboratory testing and knowledge exchange between more than 50 members and experts from over 20 countries (number fluctuating over the years) as given in the member list below. In particular, it covers interlaboratory tests and experimental aspects of bituminous binder fatigue testing, also dealing with compaction and mixture design issues, by providing background on various compaction methods and imaging techniques for characterizing bituminous mixtures. This includes a comparative validation of a new 2D imaging software. In addition, specific experimental questions and analysis tools regarding mechanical wheel tracking tests are discussed, based on comparative results from different laboratories and by applying finite element techniques. Furthermore, a concluding analysis of a long term pavement performance prediction evaluation of rutting on a test section in Austria is given, followed by an extensive analysis and interlaboratory testing program on interlayer bond testing, incorporating three different test road sections which were constructed and monitored for this purpose. Finally, regarding hot mix recycling, the key issue of reclaimed asphalt manufacturing in the laboratory is studied and recommendations for laboratory ageing of bituminous mixtures are given.

This state-of-the-art book addresses to academics and researchers, intending to serve as a help for their experimental studies and for education of young researchers.

In this sense, it is expected to be a valuable source of information for PhD students with focused interest in bituminous materials and pavements. Furthermore, the book is expected to be acknowledged by experts in standardization committees as contribution and encouragement for improving national and international standards. It will certainly be also of interest for testing laboratories and test equipment producers for optimizing their equipment and methods. Finally, it will be a technical source for road authorities, professionals and practitioners who have to solve non-routine problems.

We hope that this book will be a valuable guideline and reference for further development of bituminous materials and asphalt pavement technology.

The editors
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RILEM Members of TC 206-ATB 2004–2010 (fluctuating over the years):

Airey, Al-Khalid, Al Qadi, Allou, Ayala, Bahia, Bankowski, Bodin, Butcher, Buttlar, Chabot, Chailleux, Canestrari, Collop, De Bondt, de la Roche, Di Benedetto, De Visscher, Muraya, Freire, Farcas, Gabet, Gajewski, Grenfell, Hammoum, Hugener, Ishai, Jemiolo, Kim, Kringos, Levenberg, Loizos, Lu, Luminari, Maeck, Maliszewski, Partl, Perraton, Petit, Petros, Piber, Planche, Pronk, Raab, Roque, Rowe, Said, Scarpas, Smiljanic, Soenen, Soares, Sousa, Sybilski, Tebaldi, Vanelstraete, Van de Ven, Zanzotto.

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The following individuals were active as members or as experts in the different working groups:

- **TG1 Binders** (Convener: Sybilski, D.)
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- **TG2 Mixture Design and Compaction** (Convener: Bahia, H. U.)
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- **TG3 Mechanical Testing** (Convener: Di Benedetto, H.)
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- **TG4 Pavement Performance Prediction Evaluation** (Convener: Piber, H., followed by Canestrari, F.)
  Canestrari, F.; Chabot, A.; Collop, A.; Ferrotti, G.; Graziani, A.; Lu, X.; Maliszewski, M.; Millien, A.; Partl, M.; Petit, C.; Piber, H.; Phelipot, A.; Raab, C.
- **TG5 Recycling** (Convener: de la Roche, C)
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Contents

Chapter 1
Introduction

Manfred N. Partl and Emmanuel Chailleux

Abstract A background on RILEM interlaboratory testing is presented with some comments regarding general development and objectives for advanced testing, providing also a general overview on requirements and needs. It is emphasized that development of today is driven by the evaluation of performance based material behavior, moving more and more from semi-empirical to fundamental test methods. Given this background, an updated version of the RILEM methodology for testing of bituminous pavement materials is presented with a short discussion of basic elements. This framework is the basis for this report on the achievements of RILEM technical committee TC 206-ATB on "Advanced Testing and Characterization of Bituminous Materials". Furthermore, main principles and key elements for planning of interlaboratory tests are summarized containing points that proved also relevant for the interlaboratory tests presented and discussed in the following chapters of this book. This summary is intended as general checklist and practical tool for initiating and conducting future interlaboratory tests.

Keywords Bituminous materials • Basic concepts • General methodology • Interlaboratory testing guidelines • Planning checklist

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1.1 Background of RILEM Interlaboratory Tests

1.1.1 General

Evaluation and characterization of bituminous road materials in terms of performance related mechanical and chemo-physical properties are most important elements for generating progress and improved knowledge in application and development of bituminous road materials and systems on a global scale and in a sustainable way. In order to determine those properties, unified conclusive test methods have to be available, which are as simple as possible, efficient, refined and based on a sound physical background.

Such advanced test methods are needed as a basis for technical and economical global interaction since they allow comparing and defining the quality of materials independently of their origin and production. This is important for reducing trade barriers and for defining generally accepted state-of-the-art requirements by road administrations and road owners which also depend on a sound data basis for risk assessments and comparable life cycle considerations. In fact, unified test methods are the backbone for building up databases which are reliable and useful on a global scale. Advanced test methods are also essential for worldwide technical and scientific research interaction and knowledge exchange. They are necessary for the scientific understanding of behavior of the material and its structure from a multi-scale point of view, i.e. from small to big scale behavior. In addition, unified test methods represent also important pillars for theoretical modeling and design because they often deliver the input data and are therefore crucial for the accuracy of the theoretical predictions.

Interlaboratory testing, evaluation and characterization of bituminous materials based on their mechanical properties form a key issue to achieve the goal of unified test methods. These interlaboratory tests must be performed globally, or at least inter-continentally, in order to achieve most impact. Therefore, RILEM has devoted much of its effort in these pre-normative activities for bituminous materials during the last decades [1–10].

1.1.2 Advanced Testing of Bituminous Materials

Testing of bituminous materials has traditionally been driven by empirical and technological characterization of properties with major focus on quality assurance. Nowadays, it is generally agreed that this type of material characterization is too limited in its practical significance as input for engineering design and as tools for describing the increasing variety of bituminous materials. Hence, testing is now driven by the need of determining performance-based and performance-oriented properties that can be used not only for quality assurance but also as input for mechanistic-empirical pavement design methods. Focus in developing test methods is clearly driven by overcoming the hierarchical levels of knowledge, i.e. to manage the shift from pragmatic (empiric) to technological (semi-empiric) to fundamental (scientific) testing and characterization methods.

The objective of advanced testing can be manifold. Search for more meaningful characterization and identification of production and manufacturing quality is one major goal. This is particularly important for standardization of products and systems. The second important goal is gathering fundamental information on the intrinsic mechanisms that determine the material behavior. The third main objective is the experimental validation of models that are based on fundamental material properties. These models should be able to describe the material behavior not only under idealized lab conditions but also in other more complex situations such as lab model systems tests, full scale field tests and accelerated pavement tests. The fourth major goal is the need for improved understandings of the material performance with respect to its practical use in terms of

- environmental impact, i.e. pollution, energy consumption and health,
- functionality, i.e. mechanical resistance (stiffness, fatigue, permanent deformation, etc.), road user expectations (safety, driving comfort), chemo-physical properties (water transport, noise reduction),
- sustainability, i.e. better use of material resources such as recycling of reclaimed asphalt pavements (RAP), re-use of secondary materials, marginal materials, substitute and regenerative materials.

These many objectives demonstrate that advanced testing is not a priori identical to the determination of mechanical properties. It also comprises determination of thermal properties, mechanisms of aging (e.g. influence of oxidation, heat, UV radiation, etc.) and healing, as well as determination of material behavior in contact with other substances such as water and chemicals (e.g. special additives and agents).

Testing of mechanical properties and behavior is still very important, of course. This is true for the interaction between the different components of bituminous materials in the undamaged elastic range and, in particular, for the behavior during evolution of damage and aging, considering time and temperature dependent viscous and plastic flow with hardening as well as failure and post failure mechanisms with softening. However, aging is not necessarily a negative phenomenon, resulting in deterioration of the material which is eventually slowed down by self-healing mechanisms or life-extending treatment (e.g. rejuvenators). In particular, with emerging new generations of energy saving bituminous pavement materials, aging may also have positive effects, resulting in maturing and improvement of properties (e.g. during carefully processed curing). Unfortunately, both negative and positive aging, are not well understood yet and require special advanced test methods for in depth investigations.

Development of advanced testing has made much progress in the last decades but has also suffered some setback which cooled down the optimism as it radiated from the US strategic highway research program in the 1990s of the last century. This is true, for example, with respect to fatigue testing, Superpave shear testing and the optimism in finding one simple performance test for asphalt pavements. On the other hand, new exciting developments such as the introduction of test methods like X-Ray Computer Tomography (CT) as well as the increase of computational power for elaborating more sophisticated material models has contributed to the fact that the energy is still there.

A clear tendency can be observed towards a multi-scale approach, investigating and modeling the materials on a nano (nm...µm), micro (µm...mm), meso (mm...dm), magno (dm...dam) and mega (dam...km) scale. With bituminous materials, the nano scale is still widely unknown scientific territory, partly because of the experimental tools of today, which are of limited use for investigating these highly temperature and time dependent organic materials. For the magno and mega scale, on the other hand, the situation is different. Here, the level of knowledge is broader but in many cases only of limited general value because of the many influence factors that affect scientific testing on a 1:1 scale, such as construction parameters, climate, location, traffic characteristics and experimental costs. In fact, testing on magno and mega scale is often extremely expensive since constructing and operating test roads for destructive testing takes a lot of effort, expensive instrumentation and has to be done without disturbing the real traffic. Hence, for such tests, special linear, circular or elliptical test tracks and short road sections either in open air or in environmentally conditioned test halls have to be constructed and tortured with one of numerous stationary or mobile accelerated traffic simulators.

Generally, advanced test methods should be valid for many different types of bituminous materials, covering a broad application range in terms of temperature, strain, time etc. As far as asphalt pavement materials are concerned, they should ideally be able to cover all three basic concepts of the structural load carrying function of asphalt mixtures as shown in Fig. 1.1, i.e.

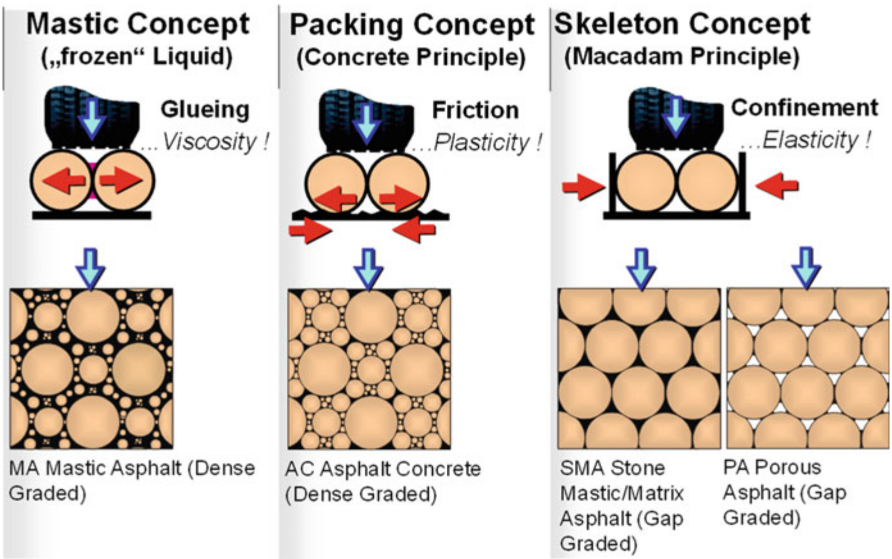

Fig. 1.1 Basic concepts for structural functioning of asphalt pavement mixtures

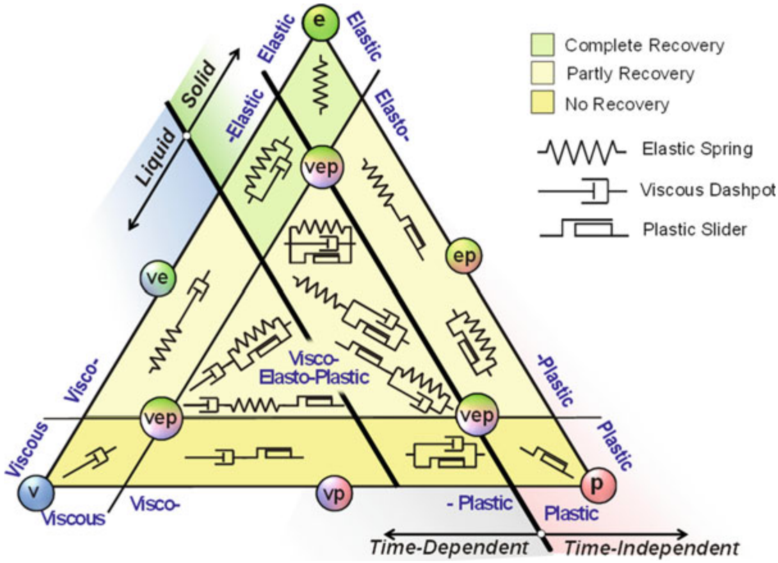

Fig. 1.2 Rheological triangle

- **mastic concept** (frozen liquid principle),
  i.e. high binder content and virtually no air voids; aggregates "swim" in bituminous mortar matrix; load is mainly carried by the binder
- **packing concept** (concrete principle),
  i.e. densest packing of aggregates with minimal binder film thickness; load carried by aggregates and binder
- **skeleton concept** (macadam principle),
  i.e. corn-to-corn contact and interlock of stones; load primarily carried by aggregate skeleton; lateral support and confinement within layer necessary.

In any case, the range of validity of application should be clearly indicated for each test method in order to avoid applying tests for types of materials they were not designed or validated for.

In addition, advanced test methods should provide information on fundamental material properties that are universal and not biased by size effects and boundary conditions of the test setup. Hence, results should be useful directly for input in mechanical and chemo-physical models and calculations. Such fundamental material properties are necessary for a wide range of multi-scale modeling of temperature and moisture dependent elastic, viscous and plastic stress-strain behavior, as depicted schematically in Fig. 1.2, as well as for modeling of damage, healing and aging. It should be noted, that the elastic spring and viscous dashpot in Fig. 1.2 are not necessarily representing linear but also possible nonlinear behavior. In the same way, the plastic slider is not necessarily perfectly plastic. These rheological models for elastic, viscous and plastic behavior may be understood as qualitative help to define certain basic phenomena of stress-strain response, such as the difference between solid and liquid or between time-dependent and time-independent behavior.

Advanced test methods should also allow clear quality assessment and unequivocal material identification (fingerprint). They are also required to be optimized in terms of measurement error. This means high precisions, i.e. providing results that are clustering closely together, as well as high accuracy, i.e. providing results that are arranging around the true value. Advanced test methods should not only be repeatable in the same lab with the same equipment, condition and personnel but also reproducible under similar conditions by other labs with other equipment and personnel. In order to reduce the risk of errors, testing should be easy to perform with minimum effort and training. Ideally, equipment should consist of simple and affordable equipment. A high degree of automation is certainly an advantage in reducing human errors, but careful check of the electronic system and validation of the software is essential, of course.

1.2 Methodology for Testing of Bituminous Pavement Materials – Basic Elements of a Testing Framework

Research performed by the RILEM technical committees on testing of bituminous materials follows a general methodology that has been presented in [5] but has been extended and refined in the following years as shown in Fig. 1.3.

The main elements of this methodology consist of four experimental fields where testing needs to be done (blue shaded areas) and two yellow shaded fields where pavement engineering is predominant. However, note that pavement engineering overlaps also most of the experimental fields as indicated by the purple shaded area. This is particularly true for identification and characterization, mix design and performance prediction as well as validation and performance tests. The different steps as shown in Fig. 1.3 can be described as follows.

The methodology starts with six preparatory steps:

1. *Fundamental scientific tests and identification.* This is basically a pre-standardization research activity that deals with acquiring experimental knowledge on new material components (binder, fibers, additives, pavements reinforcements, special aggregates, marginal materials, substitute or regenerative components, etc.) and their effect in different bituminous pavement mixtures. It includes also testing of asphalt mixtures produced in hot (146–250 °C), warm (100–145 °C), half-warm (50–95 °C) or cold technology (10–50 °C) containing reclaimed asphalt pavement material (RAP) or re-used secondary material components.
2. *Identification and characterization* of the base components (binder, additives and different aggregate fractions, reinforcement materials and other new components) and of the mixture composition (grading curve, proportions of the components including the binder). Identification and characterization

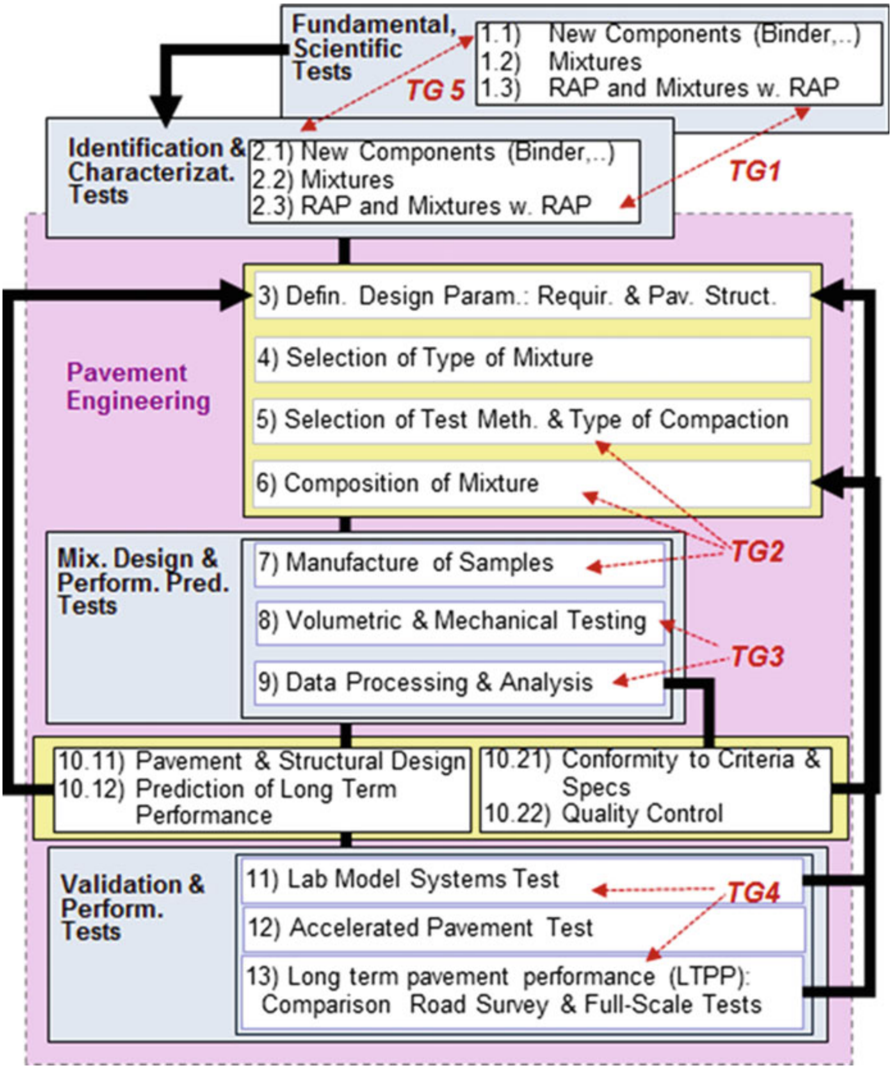

Fig. 1.3 Basic elements of a revised methodology for bituminous mixtures including the focus areas of the different Task groups of the TC 206-ATB (*blue shaded* areas are parts where testing has to be done, *purple shaded* area denotes field of pavement engineering)

testing is a type testing procedure, which has to be done for identification purposes (fingerprints) and is needed for quality control during production and for development of new products. Hence, it is not necessarily connected to specific in-field problems or requirements but it is the basis for a rough general screening of the technical possibilities during definition of the design parameters. To compare different products on a common basis, generally accepted test methods have to be used.

3. *Definition of design parameters* with respect to requirements (loading, climate, environmental aspects, life cycle, etc.) and pavement structure (including the position and function of the material in this structure) for a specific design job.
4. *Selection of type of mixture* such as asphalt concrete, stone mastic asphalt, open graded asphalt, overlays, etc. which is expected to have the best chance to meet the requirements formulated under step 3
5. *Selection of test methods as well as type and degree of compaction* suited to assess performance with respect to fatigue, permanent deformation, cracking, environmental requirements etc..
6. *Composition of mixtures* based either on experience, theoretical considerations or on the results from previous mixture design iterations.

The next three steps concentrate on mixture design and performance prediction testing and consist of

7. *Manufacture of samples*, i.e. mixing and compaction of the mixtures, final shaping and conditioning
8. *Volumetric and mechanical testing* including determination of sample composition (binder content, air voids) and testing of modulus, fatigue, permanent deformation, thermal cracking, etc..
9. *Data processing and analysis* with respect to

   – volumetric characteristics,
   – mechanical and chemo-physical characteristics,
   – environmental aspects,
   – statistical assessment.

Step 9 will lead to a set of data which can be used in one or both of the following two actions:

10.1 *Pavement design and modeling*

   – Structural design
   – Prediction of long term performance

10.2 *Conformity check*

   – Conformity to criteria and specifications as basis for quality control
   – Quality control

The use in design and prediction models (step 10.1) may finally lead to validation and performance tests, i.e.

11. *Lab model system test*
12. *Accelerated pavement testing* (APT) in the lab or in the field
13. *Long term pavement performance* (LTPP) tests in the field including

   – comparison with road survey results,
   – full-scale tests.

Steps 10 or 11–13 may lead to negative conclusions with respect to the material, and thus, the procedure needs to be repeated again with improvements concerning the selection of the base components and/or the mixture composition, eventually also affecting the selection of type of mixture and the test methods. It can also lead to a review of design parameters and pavement structure, e.g. with respect to loading or life cycle.

In the RILEM technical committee TC 206-ATB five task groups TG1 to TG5 were dealing with different subjects within this methodological framework, as indicated by dotted lines. The results of these activities are presented in the individual Chapters of this report.

1.3 Principles for Planning Interlaboratory Tests

1.3.1 General

There are already numerous documents available on how to conduct interlaboratory tests in an efficient and conclusive way. One example is the Standard ISO/IEC 17043:2010 “conformity assessment-general requirements for proficiency testing” that replaces the old ISO Guide 43 “Development and operation of laboratory proficiency testing”. It contains valuable and quite detailed information in that respect, specifying general requirements for the development and operation as well as for the competence of providers of proficiency testing schemes. Proficiency testing means the evaluation of participant performance against pre-established criteria by means of interlaboratory comparisons.

However, the ISO/IEC standard focuses primarily on the interlaboratory comparison and performance evaluation of different participants based on standard procedures and criteria. This objective is different in many ways from interlaboratory tests performed by RILEM where, instead of the performance of the different participants, the scientific, methodical search for the most accurate way of determining fundamental, physical, performance oriented material and systems properties is predominant. Hence, RILEM interlaboratory tests have a strong pre-standardization path-finder character. There is no question that the principles formulated in the ISO/IEC 17042:2010 document are also true in case of RILEM interlaboratory tests. However, since the objectives are different, strict application of the ISO/IEC standard is not always possible.

Nevertheless, it is very clear that the success of RILEM interlaboratory tests also depends on the seven key elements that have to be taken into account in a very early panning phase:

1. the aim as well as the answers and outcome that are expected
2. the systematic and methodology to be chosen
3. the selection of test methods, hypothesis and materials
4. the number and quality of participants
5. the choice and methodology of both analysis and modeling

6. the way of knowledge transfer, i.e. information and implementation regarding the outcome and answers
7. the organization as well as way and means of realization

Generally, in addition to these mostly technical key elements, ownership and other legal matters should also be defined in a very early stage. However, in case of interlaboratory tests performed by an organization, this issue may already be covered by the regulations and statutes inside the organization.

1.3.2 Checklist of Major Points

In this paragraph, a short checklist for planning and performing interlaboratory tests is given. It may help as general practical tool also containing points that proved relevant for the interlaboratory tests presented and discussed in the following chapters. Once the seven key elements of the planning phase are determined and defined, the following specific points should be further clarified:

1. Is the scope and aim clearly defined in terms of methods, materials, instruments, data to be determined or evaluated?
2. How and on whose shoulders are responsibilities distributed?

   It must be clear who is leading and managing the interlaboratory test in a technical and administrative way and who is also active member in the organizing team. An organization chart may define the different bodies that have assigned tasks, such as scientific steering panel, evaluation task force, communication and reporting body etc.. Responsibilities of the different bodies in the organizing team should also be defined. It is also important to clarify the role of the test participants within this organizational framework.
3. Who are the participants?

   This question not only needs to be answered in terms of participating persons and institutions, but also in terms of responsible people. It should also be clarified who would be responsible in case of a change of personnel.
4. What are the competences of the participants?

   It must be verified if the participants have sufficient knowhow, skills and resources to participate. This includes checking if the personnel has sufficient expertise and training for the work. In addition, one has also to explore what priority and effort the participants are willing to attribute to accomplish their work.
5. Do the participants have the necessary test equipment and devices and are all necessary tools available for data evaluation and data analysis?

   In this context the following points should be clarified:

   - Which devices and tools are used?
   - Is it ensured that devices and tools are working properly in terms of calibration, maintenance, control procedures and trained operators?

- Is the testing, data acquisition and evaluation software validated?
- Are the devices compatible with the testing guidelines?
- Do the electronic tool for data and document interchange comply with the communication guidelines?

6. Are confidentiality issues solved?

   Full success is only achieved if the participants are willing to share their knowledge, expertise, results and findings in an open collaborative scientific way. There may be restrictions of confidentiality, of course, but these restrictions have to be clarified and written down in advance. In order to avoid problems by mentioning brand names it may be more informative and of general value to describe the material through its chemical composition or, if not possible, through neutral labeling.
7. Are guidelines, clear descriptions or standards available that define precisely the testing, evaluation and modeling procedures?

   Depending on the goal of the interlaboratory test, this does not mean that everybody follows the same procedures, but each procedure considered in the test must clearly be described. Hence, the description of the procedures must be unambiguous, practicable and clear enough in order to make sure that the results are independent of the lab and personnel. This is a must in cases where repeatability and reproducibility of a procedure are of major focus.

   Unfortunately, standards are often written in way that is not based on purely technical knowledge, but on compromises of interests and the "lowest common denominator" principle. Experience shows that this often keeps too many open options, raising too many questions that often result in misinterpretations and disputes. This does not mean, of course, that descriptions of procedures should suffer from an overkill of rules, but it clearly means that decisive technical points must be precisely defined.

   In terms of guidelines and documents for an interlaboratory test, the following additional questions should be answered:

- Do the guidelines, instructions and documents comply with the goals?
- Are instructions available on how to:
  - Perform sampling?
  - Handle the specimens, in terms of transport, marking and storage?
  - Prepare the specimens for shipping and testing (including conditioning in the lab before testing)?
  - Perform the testing?
  - Communicate and interchange data and documents between the participants and the organizing team in a compatible way?
- Are all test procedures clearly described?
- Are guidelines available for data acquisition (forms, what data should be acquired) and data evaluation?
- Do guidelines exist for recording, taking notes and reporting?
- Do all participants have all necessary guidelines and documents?
- Do all participants understand the guidelines and documents?

8. How and by whom is sampling of the test specimens and materials done?
   This implies the check of the following questions:

   - Are the people who perform that sampling trained and instructed for this job?
   - If sampling is done by third party, is a representative of the participants or the organizing team present?
   - Is it ensured that all necessary information are recorded, such as location, orientation, climate, date, weather and other influencing factors during sampling, such as tools, personnel, quantity?
   - Are the samples correctly and unambiguously labeled?
   - Are the handling instructions regarding specimen transport and storage considered?
   - Is the labeled material clearly described in terms of composition, recipe, batch, dimensions, weight, age, origin, condition etc.?
   - Is it ensured that all necessary information regarding storage and the procedures for specimen preparation for each specimen are clearly documented?

9. Are retained samples set aside?
   This is an important point for different reasons. Firstly, particularly during in path-finder interlaboratory tests, new knowledge may be produced and new questions may arise which would need new specimens to be investigated; secondly new participants may join the group as the investigation goes, since interest may grow in particular when the investigation last several months; thirdly, retained specimens may be very valuable to achieve synergies with other interlaboratory tests where somewhat different questions are studied.
10. How and according to what criteria are the specimens and materials distributed to the different participants?
    This includes also the question on the kind of packaging for shipping and the question of who takes care of the shipping costs.
    In particular with bituminous materials, good expertise in packing is required due to their high time- temperature dependency. Specimens should always be packed such that no deformation of the specimen, no excessive stresses, no moistening and no interaction with the packing material during transport are created. In addition, special effort in individual labeling is needed, because some markers may lose readability over time and under transport conditions.
11. What is the time-table to perform testing, analysis and modeling?
    Fixing the time-table is particularly important in cases, where aging and conditioning of the specimens may play a role.
12. Who does the data evaluation and draws conclusions?
    This has to do with the question on how the data are presented, handled and interpreted. It deals with what evaluation methodology, statistical models and computer software are used. It also implies to ensure that skilled experts with good statistical and technical knowledge are doing the job and that these experts are supported by the participants in case of giving additional back ground input.

13. Is the intellectual ownership of the data and documents clarified?

    In case that one organization organizes the interlaboratory tests generally clear rules on this subject may already exist. However, these rules have to be communicated to everybody involved or potentially involved in the tests. In particular this raises the following questions:

    - Who owns the data and where are the data stored?
    - Who has access to the data base and under what conditions?
    - How are the data maintained?

14. How are the results and outcome communicated?

    Information and implementation regarding the outcome and answers of the interlaboratory test, in particular regarding the aim and lessons learned, is the most important issue. In this context the following points need consideration:

    - Who writes the final report and who takes authorship?

    Some organizations have rules regarding the authorship, e.g. only members of the organization can be listed as authors. These points must be clarified and communicated in a very early stage to the participants.

    - In what form are the final report and documents published?
    - How and what kind is the feedback given to participants?

15. Is the content of the final report and documents clear and properly reviewed such that it can be published in the name of the organizing team of the interlaboratory test?

    This question implies the following points:

    - Is it ensured that all documents from the participants including all information on sampling, transport, preparation, testing is available?
    - Were all the guidelines considered accordingly?
    - Does the report consider the confidentiality issues?
    - Does the interpretation and statistical analysis of the data in the report comply with the state of the art; for example, does it comply with the standards ISO 5725 on accuracy (trueness and precision) of measurement methods and results?

16. Are the questions of the costs clarified?
17. Do the participants agree and accept the procedure of the interlaboratory test?

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Chapter 2
Binder Testing

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Abstract In this chapter, a state of the art on the basics of the fatigue phenomenon of engineering materials is presented, with special attention to asphalt materials and bituminous binders. Since engineering materials are exposed to complex mechanical and environmental loadings (e.g. temperature and humidity variation etc.) asphalt mixture fatigue tests have been developed and widely used in the last decades. These tests are time consuming and relatively expensive. Hence, binder fatigue tests might be an effective preliminary evaluation of material helpful for mixture fatigue life testing.

Binder fatigue tests are used to investigate the fatigue behavior of bituminous binders and mastics, to compare different binder types, and to investigate the role of the binder in mixture fatigue behavior. The most common equipment for binder fatigue tests has been the plate-plate Dynamic Shear Rheometer (DSR). Other test geometries have been proposed as well. Even if DSR testing has become popular, there are up to now little data available on the reproducibility of this test. Task Group 1 (Binders) of the RILEM TC 206-ATB (Advanced Testing of Bituminous materials) undertook the task of organization of the RILEM Round Robin Binder Fatigue Test (RRRBFT). The purpose of this interlaboratory test was to investigate the repeatability as well as the reproducibility of binder fatigue tests.

Keywords Bituminous binders • Fatigue life • Laboratory testing • Test procedure • Dynamic Shear Rheometer • Binder - asphalt mixture comparison

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2.1 Bituminous Binder Fatigue Testing: State-Of-The-Art

2.1.1 Fatigue Phenomenon

2.1.1.1 Basics

In engineering materials exposed to complex mechanical and environmental loading (e.g. temperature and humidity variation etc.) constant micro-structural (or structural depending on material types) changes occur, causing a drop of strength. In general such effects are complex, but at macroscopic scale can be seen as so called material damage.

Depending on material type, the damage phenomena can be understood differently, e.g. in polymers damage occurs by breakage of bonds between molecules chains, in case of fibre composites it happens by the separation of fibres from composite matrix, for concrete material damage begins by debonding between aggregates and cement, i.e. from micro-cracks, in the case of wood, damage is a result of large deformations of cellulosic cells, etc.

In frame of continuum mechanics it is possible to distinguish some groups of constitutive relationships, e.g.: elasticity, visco-elasticity, plasticity. Construction materials require a combination of such relationships with an estimation of elastic or plastic material properties ranges. Apparently material fatigue (depending on material type) can occur in each range. For elastic materials it happens at atomic level while for plastic materials it happens when lines of dislocations are moved producing plastic strains. The conclusion is that these two damage mechanisms have different scales but can be treated similarly on macroscopic level via proper determination of a representative volume element (e.g. Lemaitre [28]).

In damage mechanics (e.g. Kachanov [26]) there is the possibility to distinguish some characteristic types of damage. The most important types are presented below.

Brittle damage. Brittle damage occurs when a crack is initiated without a large amount of plastic strains, i.e. the ratio of plastic strain to elastic strain is below unity.

Ductile damage. Ductile damage happens simultaneously with plastic deformations larger than a certain threshold on the graph of stress (stress norm) as a function of strain. It results from the nucleation of cavities due to debonding between inclusions and the matrix which causes local plastic instability.

Creep damage. When materials have viscous properties, damage can occur at a constant stress level. Total strains gradually increase and cause irregular inter-granular cracks.

Low cycle fatigue damage. When materials are subjected to cyclic loading with large stress or strain amplitude values, damage develops with plastic deformation in three phases: incubation, nucleation and micro-crack propagation. In case of low cycle fatigue, the damage can be either inter-granular or trans-granular.

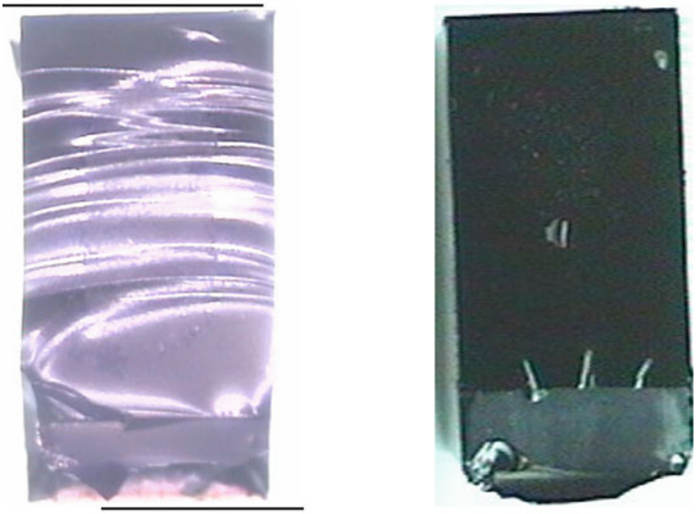

Fig. 2.1 Ductile and brittle fracture examples (Chailleux [15])

High cycle fatigue. This case is contrary to low cycle fatigue damage. Here, damage is observed for a higher number of cycles with lower amplitude of stresses or strains. Depending on material type subjected to such cyclic loading, the plastic strain at the meso-level remains small and is often negligible. Then damage symptoms can be observed at the micro-scale.

2.1.1.2 Fatigue in Asphalt Binder

In case of modified and unmodified asphalt binders it is worth noting, that depending on temperature, material can be treated as elastic or visco-elastic. For higher temperatures it is possible to assume that binder is a fluid with completely viscous properties. In this connection, for a wide range of temperatures, damage mechanisms observed in laboratory tests can differ from brittle cracking through ductile cracking up to high cycle fatigue damage (Figs. 2.1, 2.2 and 2.3). In the case of pavements which generally carry loads that are considerably lower (in normal functional state) than the load capacity, but in a cyclically repeatable way, one can assume that high cycle fatigue can occur.

2.1.1.3 Asphalt Pavement Cracking

Introduction

The most basic asphalt pavement deteriorations are permanent deformation and cracking. This order reflects also the ranking of deteriorations in the majority of world's regions (excluding cold climate regions).