To mark the approach of the new millennium, the Transportation Research Board (TRB) technical committees mounted a special effort to capture the current state of the art and practice and their perspectives on future directions in their respective areas of focus. Each of these “millennium papers” provides a comprehensive view of transportation in the United States as it exists today and can be expected to evolve as the new century unfolds.

In September 1999, the Transportation Association of Canada (TAC) released “A National Agenda for Technological Research and Development in Road and Intermodal Transportation.” The agenda identifies trends, opportunities and needs, as well as specific high priority R&D projects, relevant for advancing Canadian highway transportation. The focus of the Agenda is on identifying R&D opportunities to optimize the management of the road system and intermodal transportation, and minimize the cost of road transport while maintaining or improving safety.

To further the dissemination of current North American highway technology and future research needs, C-SHRP has prepared this special series of technical briefs, called the Millennium Research Briefs, based on information published in the TRB millennium papers and the TAC Agenda. One brief has been developed for each of the four original C-SHRP/SHRP technology areas - Asphalt, Concrete and Structures, Pavement Performance and Highway Operations.

ASPHALT BINDERS [1]

Asphalt Binder Formulation

The formulation of asphalt binders has changed significantly as a result of the new Superpave binder specifications. Under previous binder specifications, manufacturers had a great deal of flexibility in production. The Superpave mix design system provides a wide range of binder grades specifically designed to meet local climatic conditions. Consequently, binder manufacturers use higher quality crude oils and tighter process control in the formulation process. In some cases, modification techniques must be used to improve the properties of the binder, leading to increased use of air blowing, blending, chemical modification, and binder additives, such as polymers. Although traditional polymers that are compatible with asphalt have been utilized for sometime, incompatible polymers are now being chemically “bonded” with asphalt to produce new binders with reduced volatility and better in-place stability.

Chemical Characterization

The development of new evaluation techniques for asphalt is essential to improving our understanding of the chemical composition and behavior of different binders and to the development of performance-based specifications. Further development of microscopic techniques, such as atomic force microscopy
for example, will enable better measurement of binder stiffness and adhesion under different environmental conditions. New non-destructive techniques capable of evaluating binder properties as part of an asphalt concrete mix in a core or pavement structure, would contribute greatly to understanding the chemical interaction of asphalt and aggregates.

**Physical Characterization**

The physical characterization of asphalt binders has changed significantly through the development of fundamental rheological test methods as part of the Strategic Highway Research Program (SHRP). New test methods, coupled with advances in computerized instrumentation, have permitted routine quality control and acceptance testing of asphalt binders. Further research and instrumentation development are still needed, however, to understand the role of the mineral aggregate on the behavior of the asphalt binder and its importance to long-term pavement performance. New test methods are also required to allow characterization of failure properties of binders due to fatigue and low-temperature thermal cracking.

Further research is also needed to learn more about the strain distribution experienced by the binder within an asphalt concrete mixture. Improved in-situ binder characterization and computer modeling techniques will likely play an important role in advancing our understanding of this issue.

**MINERAL AGGREGATES [2,3,4]**

**Aggregate Resources and Production**

The availability of high-quality aggregates for use in asphalt pavements is a growing concern as the demand for these materials continues to rise. Existing reserves are being depleted as site boundaries are approached and aggregate specifications become more demanding. New specifications require aggregates that meet many criteria (grading, particle shape, abrasion resistance, durability) aimed at optimizing pavement performance. These tighter restrictions have led to the use of higher quality material and the generation of a higher percentage of fines during the crushing process.

Compounding this issue is the trend towards coarse or gap-graded mixtures such as Superpave, stone matrix asphalt (SMA), and open-graded friction courses (OGFCs). These mixes generally require a high percentage of well-shaped coarse aggregate and relatively low fines content. Aggregate suppliers have used shaft impact crushers in an attempt to meet the requirements of these mix designs, but they tend to produce an even larger amount of fines. As a result, aggregate producers are facing a growing inventory of unmarketable material and escalating disposal costs. Research is needed to develop new uses for excess material, to improve existing resource management and production techniques, and to determine the real effectiveness of stricter aggregate specifications.

**Aggregate Testing**

As knowledge of the role played by aggregates in pavement performance increases, the importance of aggregate testing for quality and performance will continue to grow. Pavement engineers must be able to evaluate aggregates in terms of fundamental physical and chemical properties to ensure quality and predict performance. Acceptance levels meeting the requirements of different applications need to be identified as the shift towards performance-related specifications takes place. The need to provide adequate procedures for testing aggregate quality will increase in the future as the use of recycled and waste materials expands. These materials will need to be tested to ensure quality and pavement performance are not compromised.

**NON-BITUMINOUS COMPONENTS OF BITUMINOUS PAVING MIXTURES [2]**

**Value-Added Recovered or Reprocessed Materials**

As the availability of virgin material declines and economic constraints become tighter, the use of recovered and reprocessed materials in asphalt pavements will become a necessity. Value-added materials can improve pavement performance, reduce costs by saving on new materials, or limit the adverse effects on the environment. Reclaimed asphalt pavement (RAP) is a good example of a value-added material because it can provide these advantages without hindering pavement performance. More research is needed, however, to incorporate RAP into Superpave mix design and to evaluate the benefits of other reprocessed materials.
Waste Products

For years, highway pavements have been viewed as potential “linear landfills” for a variety of waste materials created outside of the paving industry. Ground porcelain, glass, scrap tires, shingles, contaminated soils, and many others have been suggested for disposal in the paving industry. Though durable pavements have been achieved using waste materials in some cases, there is often little or no economic benefit or performance advantage. Nonetheless, social and political pressures to incorporate waste materials will continue, making it necessary to develop a standard protocol to evaluate waste materials on the basis of performance, safety, and environmental impact.

Byproducts

The production of excess fines during the aggregate production process has made it necessary to re-evaluate the effect of such material on hot-mix asphalt. Fines can have a detrimental impact on asphalt mixtures because of their impact on mixture stiffness, air voids content, and moisture sensitivity. Research needs to be focused on developing guidelines that can be used to determine a proper balance between different aggregate size fractions, RAP, and fines, without sacrificing mixture performance.

Other Non-bituminous Components

Many other non-bituminous materials have been used in asphalt pavements as a way to reduce costs and/or improve performance. These include mineral fillers, fibers, hydrocarbons, polymers, and anti-stripping agents, among others. Their use is expected to increase as natural resources are depleted and technology improves.

Mineral Fillers

- Although mineral fillers have not been used widely, their use may increase as a means to balance volumetric properties without sacrificing rut resistance in some Superpave mixtures.

Fibers

- Cellulose and mineral fibers have been used successfully as stabilizers to prevent drain down of the binder in SMA and porous friction courses.

Hydrocarbons

- Hydrocarbons, such as aromatic and naphthenic oils, have recently been used to improve the low-temperature properties of performance-graded binders required by the Superpave mix design system. Much research is being conducted to develop new additives that will not only provide better low-temperature performance, but high-temperature performance as well.

Polymers

- Polymers have been used successfully in asphalt binders for years and remain the most common non-bituminous modifier. Elastomeric polymers such as styrene butadiene rubber latex (SBR) and crumb rubber, as well as plastomeric polymers, including ethylene vinyl acetate, polyethylene, and polypropylene, are the most common forms. The use of polymers is expected to increase as more performance-graded binders are used and the technology to provide cost-effective binders improves.

Anti-stripping Agents

- Traditional anti-stripping agents, such as hydrated lime, amidoamines, and imidazolines have been used to prevent moisture damage in asphalt mixtures with good success. New research, however, is focused on developing products that create a strong bond between aggregate and binder in the presence of moisture [3].

STRUCTURAL REQUIREMENTS OF BITUMINOUS PAVING MIXTURES [4,5,6]

Mixture Properties

The ability of an asphalt mixture to provide good performance is dictated by fundamental mixture properties such as stiffness, stability, durability, and resistance to cracking. The current state-of-knowledge and research needs are discussed in the following sections.

Stiffness

The determination of mixture stiffness is fundamental to the evaluation and design of asphalt pavements. Mixture stiffness is necessary to evaluate the distribution of stresses and strains in asphalt pavements and has also been used to assess pavement damage. In addition, mixture stiffness is increasingly being used in pavement design and as an indicator of mixture quality. Much research is still required, however, to develop reliable laboratory and field test methods to determine mixture stiffness. Part of the prob-
lem stems from numerous definitions of stiffness, including resilient modulus, bulk modulus, shear modulus, dynamic modulus, and creep compliance, which all depend on the temperature, loading time, and stress state used during testing. Similar problems arise from in-situ testing where moduli measurements depend heavily on the loading pattern and pavement modeling system used. Further work is also necessary to determine the relationship between stiffness and performance, and in particular, the cost and benefits of increased stiffness.

Resistance to Permanent Deformation (Stability)
Resistance to permanent deformation is an important consideration in the design of bituminous mixtures. Stability, which can be described as the ability of a bituminous mixture to resist excessive permanent deformations, depends on the following factors:

- magnitude, frequency, pressure, and speed of loading,
- temperature,
- aggregate gradation, shape, and texture,
- binder type and amount,
- construction variables such as compaction, quality control, and segregation.

Despite knowledge of the factors affecting mixture resistance to permanent deformation, several key issues still need to be addressed. New tests and analysis procedures are needed to adequately quantify the key factors affecting stability. New models capable of predicting material behavior and performance in the laboratory and in the field are also needed. These models will require an understanding of the relationship between mixture behavior, test results, and field performance, as well as the development of constitutive relationships for bituminous mixtures at various temperatures.

Durability
Durability is critical to the long-term performance of asphalt pavements as it reflects the ability of the mixture to resist weathering from air, water, and solar radiation, as well as abrasion from traffic action. Mixture durability is normally determined by evaluating mix properties before and after environmental conditioning is applied. Oven conditioning is used to simulate aging inflicted during construction and service, while moisture conditioning is used to study the effects of water. Testing and field performance have shown the importance of low permeability as the key property of durable mixtures. High binder content, low air void content, and dense aggregate gradation all contribute to low mixture permeability. Despite this knowledge, additional research is required to develop test methods that can measure durability and predict field performance.

Resistance to Cracking
The ability of a bituminous paving mixture to resist cracking caused by fatigue, thermal variations, and movement of underlying layers in asphalt overlays is directly related to the physical properties of the mixture. A discussion of current knowledge and developments are summarized in the following sections for each of the cracking mechanisms given.

i) Fatigue Cracking
Recent work in this area has focused on improving our understanding of the mechanism of fatigue cracking. This work has shown that fatigue cracks start as microcracks at either the top or bottom of the pavement layer and later propagate and join to form macrocracks as a result of traffic loading. Additional research has identified the influence of interfacial properties between aggregate and binder on the rate of crack development as well as the role played by truck tire contact stresses in this phenomenon. These developments have led to test procedures and models that predict pavement performance more reliably. They have also led to more research aimed at developing suitable constitutive models that can describe the behavior of bituminous mixtures under different temperatures, loading rates, and aging conditions.

ii) Thermal Cracking
Thermal cracking normally initiates at the pavement surface and is caused by a severe drop in temperature or by fatigue from multiple temperature change cycles in which the tensile strength of the mixture is exceeded. Although thermal cracking has traditionally been controlled by the asphalt binder, recent research findings have emphasized the need to evaluate mixture resistance to thermal cracking using improved laboratory test methods.

iii) Reflection Cracking in Overlays
Reflection cracking in asphalt overlays is one of the most prominent problems facing the asphalt paving
industry today. Attempts have been made to improve the reflection cracking performance of overlays using stress-absorbing layers, but with limited success. Little is known about the stresses and strains that develop as a result of horizontal and vertical movements in underlying layers. More research is needed to gain a better understanding of reflection cracking and to develop test and analysis procedures that can effectively simulate the complex stress-strain behavior that exists. New materials and systems that reduce the propensity of asphalt overlays to develop reflection cracking are also needed.

**Mixture Evaluation**

One of the challenges currently facing the asphalt paving industry is the evaluation of bituminous mixtures using simple and reliable laboratory tests. A variety of tests are needed for mix evaluation during design, production, and quality control to measure fundamental mixture properties and to ensure specification standards are achieved.

Many different test procedures have been proposed for these purposes. They can be categorized as follows:

♦ Torture tests (e.g. rolling wheel tests);

♦ Simple strength tests (e.g. Marshall stability, confined or unconfined compressive strength, indirect tensile strength); and

♦ Tests that measure fundamental mixture properties (e.g. resilient modulus).

Each test has inherent advantages and disadvantages that make it effective for certain materials and loading or environmental conditions, but not others. As a result, no consensus on standard test procedures has been reached in the paving industry.

Current efforts in mixture evaluation are focused on the development of tests that measure fundamental mixture properties as they allow a variety of load and environmental conditions to be modeled. Agencies are starting to develop and use methods that characterize the resilient properties of asphalt mixtures in terms of dynamic modulus. This characterization technique provides valuable information, but is only valid at low-temperatures and rapid loading conditions. A more general approach is still needed to accommodate slower loading rates and higher temperatures. A further challenge will be to incorporate any new tests into routine procedures that can be used in pavement design.

**SUMMARY**

The current state of asphalt technology in North America has been presented; along with future research needs as outlined by the “millennium papers” of the Transportation Research Board and the national research agenda of the Transportation Association of Canada. Significant progress has been made toward understanding the behaviour and requirements for asphalt binders under SHRP and subsequent research efforts. However, many challenges still lie ahead and continued efforts of the transportation industry in Canada and the United States will help ensure that a safe and efficient highway system is available to the traveling public for the next millennium.
REFERENCES


