# Asphalt Binders

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Construction and maintenance costs for the U.S. roadway infrastructure are approximately $100 billion/year, about 1 percent of the U.S. gross domestic product. Asphalt paving is the largest component of this cost, representing about 20 percent of the total. The majority of this work is publicly funded by federal, state, and local governments—thus, ultimately by U.S. taxpayers. This work and a great deal of commercial work is done primarily according to state agency specifications, which define the characteristics of the materials used and the attributes of the finished pavement. Because these projects usually are built under low-bid contracts, rational performance-based specifications are critical for producing cost-effective pavements. For most asphalt pavements, the newly implemented Superpave specification system is used.

About 95 percent of the paved roads in the United States are surfaced with asphalt, and most are produced using hot-mix construction. Hot-mix pavements consist of one or more compacted layers that contain (volumetrically) about 80 percent mineral aggregate, 15 percent asphalt binder, and 5 percent air voids. In the United States, the asphalt binder component is valued at approximately $3 billion/year and can have a disproportionately large impact on overall pavement performance.

The asphalt binder functions as an inexpensive (typically, $0.05/pound), waterproof, thermoplastic adhesive. In other words, it acts as the glue that holds the road together. In its most common form, asphalt binder is simply the residue from petroleum refining. To achieve the necessary properties for paving purposes, binder must be produced from a carefully chosen crude oil blend, and processed to an appropriate grade. For a few applications, additives (usually polymers) are blended or reacted with the binder to enhance its properties.

## ASPHALT REFINING AND FORMULATION

Asphalt binders are produced mainly by petroleum refiners and, to a lesser extent, by formulators who purchase blending stock from refiners. Until recently, binder specification systems were relatively lenient, and gave refiners a high level of production flexibility. Therefore, refiners tended to view asphalt as a simple, convenient way to use the residual material from the refinery operation. As a result of the new Superpave specification system, asphalt refiners increasingly perceive asphalt as a value-added product. It also has caused many refiners to reevaluate their commitment to asphalt production; some have made a strategic decision to de-emphasize or cease asphalt production, though others have renewed their efforts to produce high-quality binders.

The production of asphalt binder consists of two phases: refining the asphalt base stock and formulating this stock into a finished asphalt binder. As a result of the new Superpave specifications, both phases of production require increased logistical control and greater attention to quality. Also, focus on asphalt's environmental, health, and safety characteristics has increased. This emphasis has created a demand for asphalt binders with improved, lower volatility, a characteristic that can be affected by both the refining and the formulation phases.

The refining phase uses relatively mature technologies, and significant changes in these technologies are not expected. However, the new specifications have created a need for more judicious crude oil selection and tighter process control. Because most asphalt crude oils are imported, unforeseen political events may affect the future availability of these crude oils and may pose unexpected challenges to the industry.

Although changes in the refining phase have been relatively minor, changes in the formulation phase have been substantial. These changes have been driven, in part, by the wide range of binder grades required by the Superpave system. This range of grades enables binder performance to be closely matched to climatic conditions. Binders necessary for severe climate regions cannot be made from crude oil alone; they must be modified. The modification improves the properties and increases the cost of the binder.

The Superpave specifications also have changed the way that modification systems are selected. In the past, some additive systems were heavily promoted to state agencies, sometimes based on novel testing protocols. If the state agency was convinced of the benefit of a particular additive system, it often would implement a restrictive specification that functionally excluded competitive products. Now, because the new specification system is intended to be blind to modification technique, additive systems are forced to compete on a more equal basis.

Implementation of the Superpave system has increased the use of unconventional binder additives, air blowing, blending, and chemical modification. These changes will challenge the industry to show that binders produced by different means to similar specifications can perform equally well. As the relationship between binder properties and mixture performance is better understood, the specification will continue to evolve. New and more cost-effective modification technologies also will be developed, and the use of custom blending and modification will increase. In combination, these trends will cause additional supply changes, as binder producers seek to match their strategic resources and interests with the most appropriate niches in the asphalt market.

## CHEMICAL CHARACTERIZATION

Understanding the chemistry and microstructure of asphalt is critical in the development and improvement of performance-based specifications. The environmental factors that cause asphalt oxidation and moisture-associated effects, for example, vary across the United States. The conditioning schemes used in the specifications need to reflect the environment more accurately. Therefore, existing oxidation models must be modified and new models must be developed to reflect the effects of moisture on asphalt pavements.

New techniques are being developed to evaluate the phase behavior of conventional (that is, unmodified) and modified asphalts. Among these are microscopic techniques such as atomic force microscopy. This powerful surface-analysis technique has a three-dimensional spatial resolution in the angstrom range. Advances in this technology enable the measurement of mechanical properties such as local stiffness and adhesion under temperature and environmental controls. As the use of such techniques increases, finer resolution and shorter scan times are anticipated.

Asphalt modification recently underwent a major transformation. Polymers composed of functional groups that are compatible with asphalt have been formulated. Other traditional polymers that are incompatible with asphalt are being chemically “bonded” with the asphalt. These “grafted” polymers offer better storage, handling, and in-place stability characteristics than asphalt alone. Future application of polymers may entail matching polymer properties with anticipated in-service physical requirements (e.g., thin overlays, overlays on concrete, or full-depth pavements).

Future research needs to address how and when asphalts with similar physical properties but dissimilar chemistries will perform under various service conditions. Most crucial is the interaction of asphalt and aggregate, particularly with the fines, which contribute the overwhelming majority of surface area in a mixture. To adequately address these issues, nondestructive techniques must be developed for evaluating binder properties in loose mix, cores, and even pavements.

## PHYSICAL CHARACTERIZATION

Test methods and specifications for asphalt binders remained relatively unchanged for more than half a century, until the introduction of viscosity-based specifications in the late 1960s. Research as part of the Strategic Highway Research Program (SHRP) had a significant impact on the characterization and specification of asphalt binders with the development of new, more fundamental test methods. The widespread use of fundamental rheological test methods became possible in the 1990s. New advances in instrumentation and the widespread application of personal computers permitted the routine application of rheological methods for use in conducting research and in determining specification compliance.

Testing for quality control and acceptance probably will continue to focus on the bulk properties of asphalt binders, even though the presence of the mineral surface is widely accepted as altering the bulk properties. Future developments in test methods and instrumentation will undoubtedly provide the tools for understanding the role of the mineral surface in the behavior and durability of asphalt binders. In situ characterization will be necessary to fully understand the interaction between asphalt binders and the mineral surface as well as its importance to mixture and pavement performance.

Currently, little is known about the strains and, more importantly, the distribution of strains encountered by the asphalt binder within the asphalt mixture. These considerations are essential to understanding the need for nonlinear instead of linear modeling and testing of asphalt binders, as well as the need to consider nonlinearity in both research and specification applications. Improved computer modeling techniques, in situ characterization of asphalt binder behavior, and imaging techniques will undoubtedly play a role in settling these controversies. The dichotomy between specification testing and testing for the purposes of research studies probably will continue, especially as specification testing is recognized as a means for buying and selling an item of commerce.

Although rheological properties are important for predicting the performance of asphalt binders, the characterization of failure properties is also necessary. New test methods will be required to define the fatigue behavior as well as the cracking and healing characteristics of asphalt binders. Three modes of distress are recognized in the current binder specifications: rutting, fatigue, and single-event low-temperature thermal cracking.

Thermal fatigue, its coupling with load-associated fatigue, and reflective cracking are not considered. These issues must be addressed in research studies and in future test methods and specifications.

## SPECIFICATIONS

SHRP research created a new awareness of the need to treat asphalt binders as a sophisticated material rather than a low-cost commodity. The SHRP research and its resulting products represent works in progress, not final answers. In the coming years, studies on the basic composition and structure of asphalt binders—both unmodified and modified—will continue. These studies will influence specifications and test methods, allowing the continued development of more rational specifications that better relate the basic nature of asphalt binders to performance.

Advances in instrumentation will allow the more rapid characterization of the chemical and physical properties of asphalt binders. As a result, binders increasingly will be custom-made for specific applications, especially as warranted construction becomes more prevalent. The trend toward performance-based specifications will accelerate, as will the need for increased involvement in and understanding of binder properties and pavement performance by researchers, contractors, and hot-mix producers. Custom-made and special materials will be used by contractors as per European experience, and the binder increasingly will be treated as part of a system, integrated with the design and selection of mixtures and with pavement design.

## LIFE-CYCLE COSTS

Pavement construction requires many materials and operations, which are supplied by several independent industries. The process involves numerous explicit and implicit design decisions, all of which can affect the life-cycle cost of the pavement. Design decisions must be made regarding

- Binder formulation;
- Binder grade;
- Aggregate type;
- Mix design ratio (i.e., aggregate gradation and binder content);
- Structural design (thickness);
- Production tolerances;
- Anticipated maintenance strategy; and
- Expected pavement life.

The implicit design decisions (e.g., binder formulation) are made by companies that supply the materials or perform the construction and are guided by specifications. If the specifications are truly performance-based, then products and services can be reliably purchased on a low-bid basis. Therefore, design optimization requires the use of true performance-based specifications for the materials and processes used.

The explicit design decisions (e.g., binder grade) are made by the pavement designer and usually are based on design guidelines. Historically, these design decisions were considered independently, on the basis of anticipated needs imposed by traffic and climate. However, in reality, multiple tradeoffs could be made among these design variables, and the potential to exploit these tradeoffs is only beginning to be realized. For example, it may be possible to

- Improve pavement thermal cracking resistance by specifying either a thicker pavement or a binder with better low-temperature properties,
- Improve pavement fatigue resistance by specifying either a thicker pavement or a binder with better fatigue resistance, and
- Improve rutting resistance by specifying either a more angular aggregate or a binder with better high-temperature properties.

To maximize the life-cycle cost of pavements, tools are needed to understand how each design decision affects overall system performance. The potential to accomplish this goal is only beginning to be explored and will be realized only when explicit models are developed that relate binder, mixture, and pavement properties to performance. We anticipate that this area will be a major source of cost and performance improvements and as such will become a primary focus of future research.

## PUBLIC POLICY CONSIDERATIONS

In the United States, about 4 percent of all public sector spending (by federal, state, and local governments) is used to build and maintain the nation's network of roads and highways. It is in the public interest to spend this money efficiently, for example, by producing roads that have the lowest possible life-cycle costs. This goal can be reached only through research.

U.S. spending on highway research is extremely low. A detailed 1994 analysis indicated that U.S. spending for industrial research and development (R&D) averaged 3.8 percent of sales (varying between 0.6 percent and 13.5 percent among the 39 industry groups analyzed). In contrast, the Federal Highway Administration's Strategic Transportation Research Study estimated highway R&D spending at 0.17 percent. The five-year SHRP study only increased this by about 0.05 percent. The inescapable conclusion is that the U.S. highway industry lags far behind other industries in research spending.

Only a small portion of highway research is privately funded. The decision to fund this research is based primarily on a corporate profit motive, and the research is focused mainly on meeting existing specifications at the lowest possible cost. Private-sector research usually is viewed as either a competitive tool or a cost of doing business, and companies that underfund research often find themselves at a competitive disadvantage.

The great majority of highway research is publicly funded, and this research is critical for both defining appropriate specifications and enabling cost-effective design decisions. However, because a traditional profit motive does not exist in the public sector, funding for research depends on the wisdom and foresight of lawmakers and administrators, who often are faced with more immediate and tangible needs. In the public sector, the cost of underfunding highway research can be an overpriced and underperforming highway system.

In the long term, the increased use of design/build/maintain contracting might begin to address these issues. Under such a system, only pavement performance is specified, and responsibility for achieving and maintaining the desired performance level is assumed by a single contractor. This arrangement essentially delegates all design decisions to the contractor, who then has a profit motive to optimize the overall system. This kind of innovative contracting probably will be more widely used in the future; however, it will be limited in the short term by a lack of companies with the necessary expertise and resources. Publicly funded highway research can facilitate this transition by developing a high-level technology base, which in turn would promote competence and competition among potential bidders.

Our nation’s highway system provides important economic benefits but also consumes a significant portion of public funds. As a society, we have an interest in improving both the economic performance and efficiency of this system. Many questions remain unanswered regarding the asphalt pavements that we use to build and maintain our highways. Focused investments in research and technology can answer these questions and return large dividends to the taxpayers who pay for and use the system.