NEW ASPHALT PAVEMENTS FOR A NEW CENTURY

By Tom Kuennen

New technologies in asphalt provide new options in meeting durability, environmental, and cost challenges

A bituminous 'Perpetual Pavement' section is placed on Ohio's I-77.

As the Eisenhower National System of Interstate and Defense Highways marks its 50th anniversary, new, durable asphalt pavement designs are revolutionizing Interstate and National Highway System pavements. A new generation of asphalt pavement design is standing up to unprecedented traffic loads and is changing how government transportation agencies specify hot mix asphalt (HMA) and how asphalt contractors place it.

These new mix and pavement designs include Superpave®, the performance-driven asphalt pavement designs developed in the United States; stone-matrix asphalt (SMA), a super-durable design imported from Germany; polymer-modified open-graded friction course (OGFC) asphalt pavements, which reduce tire spray and attenuate pavement noise; the new Perpetual Pavements, an HMA pavement structure design that competes with portland cement concrete (PCC); and the new "warm" asphalt mixes, which will quell energy costs and reduce potential emissions.

Here's a look at how asphalt pavements are changing at the start of the 21st century.

Flexible Pavements of Ohio photo

Shift to Performance Specs

The most significant change in HMA has been a shift from conventional "Marshall" mix designs, in which the liquid asphalt's viscosity or resistance to penetration by a weighted needle is the basis of the "recipe" for an asphalt mix, to performance-related Superpave binder mix designs, in which different liquid asphalts are matched with select aggregates to perform durably given projected traffic loadings and extremes of climate.

In other words, the basis of the mix design has changed from a simple test of the liquid asphalt's "thickness" to a system that takes into account the chemistry of the liquid asphalt and variability of constituent aggregates, and engineers them to perform under local traffic and local weather extremes. From scratch, the paving mix is designed to stand up to the twin punishments of traffic and weather, which vary tremendously from project to project, region to region.

This shift to Superpave has stimulated a profusion of new types of lab and field mix testing equipment, new full-scale accelerated pavement testing facilities, and has supported a new class of technically trained lab technicians. A growing database on HMA mix performance is being used every day to make mix design decisions and improve long-term HMA performance.

Superpave is an acronym for SUperior PERforming Asphalt PAVEments and was the No. 1 product of the Strategic Highway Research Program (SHRP, 1988-1993), a five-year, $150 million - program paid for by the state departments of transportation. Nearly one-third of the $150 million was spent on asphalt research in an effort to develop performance-based specifications that would relate material properties of the binder and the mix to field performance. The funds were provided by each of the 50 states via a 0.25 percent "take-down" from the federal-aid highway funds to carry out the research program during the five-year period covered by 1987's Surface Transportation Assistance Act (STAA '87).

Basically, liquid asphalt is what remains of a barrel of crude oil after gasoline, plastic feedstock, naptha, and other lighter hydrocarbons have been extracted during refining. Because crude oil is sourced all around the world, its chemistry varies widely. It's now recognized that performance-related mix designs like Superpave may require enhancement of the liquid asphalt to meet the demands of traffic and climate, so the performance of today's liquid asphalts is being bolstered by a new generation of asphalt modifiers, thus bettering the performance of Superpave mixes, OGFCs, and thin-lift overlays.

There are three elements to Superpave mix design: an asphalt binder specification geared to pavement loadings and local climate; a volumetric mix design and analysis system; and mix analysis tests and a performance prediction protocol including historical climatic database, software, and environmental and performance models.

Volumetric properties of Superpave include its percentage of air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA). Superpave's volumetric mix design system balances aggregates, asphalt, and voids with the ultimate goal of producing durable mixes that resist rutting.

Superpave is different because the type of Superpave design used depends on the project's anticipated traffic loadings and regional average historical climate. There are four levels or families of mixes for Superpave, depending on the anticipated loading, and classified according to the number of motions or gyrations the mix receives to compaction in the Superpave gyratory compactor lab test device.

Level 1 mixes have a design compaction level of 50 gyrations per specimen in the gyratory compactor and are used for low-volume pavements of under 300,000 equivalent single-axle loads (ESALs). Level 2 mixes need 75 gyrations and are used for 0.3 million to 3 million ESALs; Level 3 mixes, 100 gyrations, 3 million to 30 million ESALs; and Level 4 mixes, 125 gyrations for in excess of 30 million ESALs.

With the implementation of Superpave performance specs by the California Department of Transportation (Caltrans) beginning in January 2006, all states of the union will have adopted Superpave as a standard spec, if not the only spec allowed for state DOT paving projects. And Superpave use is spreading through municipal and county specs as well.

SMA = Super-Strong Pavements

Complementing Superpave is SMA, stone-matrix asphalt. SMA is a "gap-graded" mix design that brings together strong, coarse aggregate and a high content of as much as 6 to 8 percent of asphalt cement. The gap-graded design has fewer fines than conventional HMA, about 15 percent of aggregate weight. The outcome is a strong HMA mix with a stone-on-stone skeleton that easily resists rutting.

There are drawbacks to this structure, however. Because the gap-graded mix lacks medium-sized aggregate, conventional low-penetration-grade asphalt used in other mixes can drain out of the coarse aggregate skeleton. To avoid this "drain-down," SMA mixes use cellulose fibers or other modifiers to hold the binder in place.

The acronym, SMA, is derived from the German term splittmastixasphalt; the Americanized "stone-matrix asphalt" means much the same thing. While other central and northern European countries claim to have invented SMA mix — as do some Americans — the design appears to have been first used in Germany in the 1960s to resist damage from studded tires. Its virtues soon proved to include exceptional resistance to shoving and rutting as well.

Since SMA's introduction in 1990, half the states are using SMA in wearing surface course applications. The states of Georgia and Maryland, which are taking an active role in SMA development, are increasing their use of SMA and are alerting other states.

Under equal conditions, SMA outlasts Superpave, with a life expectancy of anywhere from 20 to 30 percent longer than a conventional dense-graded HMA pavement. However, it's more

Asphalt Institute Image

expensive than Superpave, by as much as 10 to 30 percent, to as much as 50 percent higher, by some estimates, than traditional HMA mixes.

Quieter OGFCs

Today, HMA open-graded friction courses (OGFCs) are providing safer pavements through enhanced surface drainage and by reducing pavement noise.

These drainable OGFCs offer road agencies a better-performing, driver-friendly pavement with an "open" aggregate structure (without fines) in which larger-sized aggregate is held in place by polymer-modified and fiber-modified performance-graded liquid asphalts, but at a 30 to 40 percent cost premium over conventional asphalt mixes.

A new wave of OGFC pavements being built here and in Europe have considerably higher air void contents than the first generation of OGFCs in the 1970s, today in the range of 17 percent to 22 percent.

The open structure of voids allows water to drain right through the driving or friction course to an impervious intermediate course below, and out into roadside ditches. The result is the elimination of tire spray and hydroplaning.

Because noise generated at the tire/pavement interface is attenuated within the spaces between the aggregate, they are significantly quieter pavements. The noise reduction can be on the order of three to five decibels, representing at least a 30 percent decrease in volume. And the frequencies of tire whine are reduced as well, producing a less annoying sound.

The Arizona Department of Transportation is nearing the end of a three-year, $34 million project to surface about 115 miles of Phoenix-area freeways with asphalt-rubber open-graded pavement, to provide smoother rides for motorists and quieter neighborhoods for those who live adjacent to the roads.

Research from the Texas DOT supports the use of open-graded asphalt pavements in that state. There, a recent asphalt rubber "porous friction course" overlay of a concrete interstate in San Antonio substantially reduced noise levels, improved its ride quality by 61 percent, and increased the skid resistance by 200 percent, according to Texas DoT.

However, in addition to their cost premium, OGFC pavements can clog with roadway fines over time, reducing their drainage qualities. Due to their higher cost and tendency to clog, engineers suggest OGFCs be used on high-volume, high-speed roadways such as Interstate highways, where their higher cost can be rationalized, and where the suctioning action of the tires on the pavement tend to pull detritus from the porous lift. Open-graded pavements on lower-volume, slower-trafficked local roads have been less successful.

Porous Asphalt for Parking Lots

New "porous asphalt" pavement designs – not to be confused with OGFCs – permit quick drainage of storm water to catchment areas and help remove roadway pollution from the storm water stream. As such, they can help local government agencies meet EPA Phase II storm water pollution requirements now in effect for smaller governments.

Period advertising from the asphalt industry stressed that asphalt is the preferred choice for overlays, and urged building roads of it to begin with.

While not appropriate for freeway or even local road use, they provide passive water treatment by absorption of runoff into adjacent soils, where microbes decompose these nonpoint surface pollutants – such as latent oils, greases, and other materials – before they can reach groundwater or surface waters. Thus they also assist in recharge of groundwater aquifers.

In 2004, in Lenexa, Kan., city public works officials built a porous asphalt parking lot in an environmentally sensitive area near a constructed wetland, a 325-acre lake, and a stream restoration project, all part of a new city park. There, above a reservoir, an underdrain system was placed below a 4-inch-thick, open-graded mix with a polymer-modified PG 76-22 binder.

"Soon after we finished the project there was a heavy downpour," said Larry O'Donnell, vice president of O'Donnell & Sons Construction. "I was impressed to see how water ran right through the porous pavement, just as it was supposed to."

Perpetual Pavements: The Future?

As the 21st century began and the HMA industry contemplated how to make more durable asphalt roads last for decades without major reconstruction, it also considered the competitive situation between HMA and portland cement concrete (PCC) pavements.

Asphalt promoters had long been stung by the assumption that HMA was cheap but not long-lasting, and that PCC was more expensive but longer-lasting. Could the industry perfect an asphalt

pavement design that would last as long or longer than a PCC pavement, and still be cost-competitive with PCC?

The answer was the Perpetual Pavement concept, launched at the turn of the century by the Asphalt Pavement Alliance (APA) as a strong pavement structure design to compete with PCC.

The Asphalt Institute, the National Asphalt Pavement Association, and the State Asphalt Pavement Associations, an umbrella group representing local associations in 36 states, comprise the APA, whose mission is promotion of asphalt and the Perpetual Pavement philosophy.

Perpetual Pavements are designed with thick layers of HMA of different mix formats, with a sacrificial driving course on top. This driving or friction course is intended to be periodically cold-milled and overlaid with more HMA to restore condition. The surface can be cold-milled and repaved at night, minimizing traffic congestion and its impact on commuters and road workers.

Perpetual Pavements are designed and built from the bottom up, with a lower layer designed to resist bottom-up fatigue cracking. The middle layer uses an asphalt mix designed to support anticipated traffic loads, and the top layer may be of any HMA mix design.

"We now have the capability of designing the most cost-effective mix using local materials, selecting the appropriate mix type for the traffic conditions and environment," said National Asphalt Pavement Association (NAPA) President Mike Acott. "Through an understanding of the interrelationships between material characterization, pavement thickness, fatigue, and rut resistance, we are able to develop Perpetual Pavement structural designs that result in the lowest life cycle cost."

Sound Engineering Principles

When fully implemented, Perpetual Pavements will perform with reliability because they are based on sound engineering principles.

These principles are articulated in a concept paper titled "Perpetual Pavements," by Jim Huddleston, P.E., Asphalt Pavement Association of Oregon; Mark Buncher, Ph.D., P.E., The Asphalt Institute; and David Newcomb, Ph.D., P.E., National Asphalt Pavement Association.

With Perpetual Pavements, typically there are three asphalt layers:

- a durable, fatigue-resistant base layer;
- a rut-resistant and durable intermediate layer; and
- a rut-resistant, impermeable, and wear-resistant surface layer.

The materials and mix design used in each layer comprise the key to successful Perpetual Pavements. With Perpetual Pavements, the material in each asphalt layer is specifically designed to resist pavement distresses. The outcome is a thinner overall section than those utilizing a conventional long-life design.

With this design, the potential for traditional fatigue cracking may be reduced, and pavement distress may be confined to the upper layer or surface of the structure, Huddleston et. al. write. "Thus, when surface distress reaches a critical level, an economical solution is to remove the top layer or surface course and replace it.

Photo courtesy of Tom Kuennen

Illinois Asphalt Pavement Association photo

Top: Perpetual Pavement is placed on Interstate 70 in eastern Illinois. Above: "Warm" asphalt mix is placed during a 2004 demonstration for the asphalt industry.

PHOTO COURTESY OF TOM KUENNEN

"Most pavement design procedures do not consider the characteristics of each pavement layer relating to fatigue, rutting and temperature cracking," the engineers write. "Since each pavement layer has its own part to play in performance, a new structural design method is needed to analyze each pavement layer. The mechanistic-empirical approach meets this need."

With mechanistic design, they write, "knowing the critical points in the pavement structure, one can design against certain types of failure or distress by choosing the right materials and layer thicknesses. In the case of a perpetual pavement, this consists of providing enough stiffness in the upper pavement layers to prevent rutting and enough total pavement thickness and flexibility in the lowest layer to avoid fatigue cracking from the bottom of the pavement structure."

Recycling Old Pavements

The easy recyclability of HMA is transforming the HMA industry, and reuse of aged asphalt has become common throughout the country.

Long before environmental issues became popular, asphalt pavements were being recycled as granular aggregate for road base, as embankment fill, and in pavement driving and base courses.

Today, specialized milling machines plane off aged, cracked asphalt pavement in varying depths and widths, and convey this reclaimed asphalt pavement (RAP) to dump trucks that haul to stockpiles. From there, it's reused as inexpensive road base, added to virgin HMA as a tested material, used for driveways, bike paths, recreational trails, and much more.

With approximately 80 percent of asphalt pavement removed from resurfacing or widening projects reused in new road construction, asphalt pavement is the nation's most widely recycled product, according to APA. Use of RAP saves resources, time, and cost, as those existing aggregates don't require extraction, loading, crushing, screening, or hauling, among other things.

In making HMA, the RAP then may be further crushed, proportioned, heated, and blended with a small amount of new materials, then mixed to meet pavement specs. RAP can be incorporated into HMA in both drum mix and batch plants.

RAP's asphalt content varies from 3 to 7 percent by weight. The RAP asphalt tends to be harder than new asphalt binder, because of the effects of prolonged oxidation and weathering. This residual asphalt in the RAP may be reused by addition of rejuvenating chemicals, or heated and combined with fresh liquid asphalt at the plant.

As a result, RAP now is accepted in asphalt paving mixtures as an aggregate substitute and as a portion of the binder in nearly all 50 states. Substitution rates of 10 to 50 percent or more, depending on state specifications, are normally introduced in pavements, and recently developed technology has even made it possible to recycle 90 to 100 percent RAP in hot mix. And experience so far shows that RAP can be used in Superpave mixes predictably and reliably, so long as the unique properties of the RAP used are tested and known.

There is great interest among contractors in new asphalt technologies. Here, hundreds of contractors view a "warm" HMA mix demonstration following the 2004 World of Asphalt show in Nashville.

Foamed Asphalt Bases

Yet another application of recycled asphalt is foamed asphalt, a cost-effective way of in-place stabilization of road bases that's gaining interest from coast to coast. Foamed or "expanded" asphalt is created by carefully injecting a predetermined amount of water into hot penetration-grade asphalt in the mixing chamber of a pavement recycling/remixing unit, and offers a cost-effective alternative for road base stabilization from asphalt emulsions or cement slurry.

The expanded asphalt has a resulting high surface area available for bonding with the aggregate, leading to a stable road base using 100 percent of the existing in-place materials. The benefit is substantial cost savings over use of asphalt emulsions for base stabilization, and complete elimination of the cure or "break" period. While foamed bases usually are topped with hot mix asphalt or seal coat, they can bear traffic almost

Wirtgen America Inc. photo

Milled RAP is the No. 1 recycled material in the United States.

immediately after grading and compaction, including heavy trucks.

Foamed asphalt is produced by adding small amounts of water (approximately 2 to 3 percent by mass of asphalt) to hot liquid asphalt, typically 320 to 350 degrees Fahrenheit. The liquid asphalt used for the process can be straight penetration- or performance-graded. When injected into the hot liquid asphalt, the water evaporates abruptly, thus causing extremely rapid expansion of the liquid asphalt in the saturated steam. Typically, the liquid asphalt expands to 15 to 20 times its original volume. The intensity and effectiveness of the foaming process can most effectively be governed by controlled operation of the basic physical conditions, such as pressure and temperature. Precise addition of water allows control of the rate and amount of expansion.

When using foamed asphalt as a binding agent, the content of fines in the aggregate is very important. The foaming process results in a surface expansion of the liquid asphalt and a simultaneous reduction of its viscosity. The dispersion properties of the liquid asphalt are greatly increased, ensuring that the fines (0.075 sieve) in the aggregates are coated.

This filler and the foamed asphalt together produce a mortar, which binds the coarse aggregates. On the projects where recycling depth is limited, omitting the existing road base, insufficient fines are generated (10 to 20 percent 0.075 minimum) and it's necessary to add fines, as dry portland cement, lime, fly ash, or a slurry of the same.

Warm Mixes Reach the United States

Another new "twist" in asphalt mix chemistry that is gaining interest – if not market share – is another import from Europe, so-called "warm mix" technology.

Warm asphalt mixes were introduced in a big way to the United States at an open house and demonstration following the World of Asphalt expo in Nashville in 2004. There, warm mixes were created in-plant and placed before hundreds of contractors and engineers.

With warm mixes, asphalt contractors and specifiers are getting closer to a low-emissions asphalt mix that should make siting and "permitting" of asphalt plants easier, and may allow construction of pavements in colder weather because contractors may no longer fear critical loss of temperature in the cold. The result may be a longer construction season extending into the winter in some regions of the country.

They may permit trucking of loads of asphalt over longer distances, without fear of critical loss of temperature, allowing contractors to expand market areas.

That's because warm asphalt mixes are heated to a temperature well below the 300-plus degree Fahrenheit temperatures of conventional HMA. This lower temperature has the potential for reduced plant emissions in different stages of production, longer compaction times in the field, and reduced energy consumption in the plant. Warm mixes can allow faster construction of pavements made up of deep lifts of asphalt, for example intersections, which need to be opened as soon as possible. Because the mix is not so hot to begin with, less time is required to cool the mix before the next lift is placed.

A new warm-mix additive sourced from the United States, Evotherm, is claimed to be compacted at temperatures as low as 140 degree Fahrenheit. This product is undergoing testing at the test track of the National Center for Asphalt Technology (NCAT) at Auburn University.

However, this convenience comes at an added cost. In 2006, the benefits of warm-mix technology will be available only through proprietary products – sometimes only through exclusive licensing – and command a premium in cost per ton, depending on volume, of as much as $3 to $4 by one estimate.

NAPA seeks to answer a variety of questions regarding warm mixes, including whether they can be opened to traffic as quickly as conventional asphalt pavements, a major advantage of asphalt.

NAPA asks how will they perform in the long term, and if the European-sourced warm mixes will perform under North American climate extremes. Study continues at NCAT in Alabama.

The Asphalt Institute's Historic Role in the Interstate Highway System

By Bernie McCarthy, P.E.

The Federal-Aid Highway Act of 1956, signed by President Dwight D. Eisenhower, created a dedicated source of funding for the Interstate highway system. The funding was established through the federal gas tax and thus began arguably the greatest public works project ever undertaken anywhere in the world. A 41,000-mile Interstate system was the heart of the program that would connect major population centers in the United States.

From its inception in 1919, the Asphalt Institute has been a spokesman for the asphalt industry through programs of engineering, research, and education. The Asphalt Institute's Board of Directors recognized that asphalt should be a major factor in Interstate construction. The Institute began to educate state highway engineers on the advantages of asphalt paving and initiated a series of meetings in each state to present asphalt's cost effectiveness, safety, life expectancy, and maintenance attributes as the most efficient choice.

The Asphalt Institute Board of Directors also established special funds for a communication program that included both national and regional advertising campaigns and for the addition of field engineers to promote the use of asphalt pavements for Interstate highways. The advertising program was designed to reach both general public and engineering audiences. General public ads, for example, were carried in *Life* magazine, *U.S. News and World Report*, the *Wall Street Journal* and CBS radio. These ads informed motorists about the many benefits asphalt pavements provide to make their ride comfortable and enjoyable. Engineering audience ads were carried in publications such as *Engineering News Record, ASCE Civil Engineering, American Public Works, Roads and Streets,* and local construction journals. They featured the design advantages of asphalt, the favorable economics when compared to alternative pavement types, the speed and ease of construction, and the ability to maintain an asphalt pavement much more readily than an alternate type. These ads served multiple purposes by depicting current solutions and practices while also providing design engineers a basis to compare their own designs for traffic, terrain, soil type, environment, and materials indigenous to their location.

The complement of Asphalt Institute Field Engineers was increased to essentially locate a Field Engineer in each state to provide extensive educational programs on a whole gamut of topics pertaining to asphalt pavements to assist in the development and construction of this type of pavement.

Shortly after the Interstate construction program began, the AASHO Road Tests were conducted in Ottawa, Ill. The Institute created a Special Projects section to analyze and transfer the technology developed on the Road Test. Rising out of that analysis came validation of the Full-Depth and Deep Strength Thickness Design concepts for asphalt pavements that were then promoted by the Asphalt Institute. Prior to this time, thin asphalt pavement layers were placed on top of a thick granular base. With the advent of these Full-Depth and Deep Strength philosophies, the thickness of the typical asphalt section increased three- to four-fold and proved to be a far superior pavement.

An additional problem, still true in some cases today, is that traffic projections for the design life of the pavements and the percentage of trucks were greatly underestimated. One distinct advantage of an asphalt pavement is that it lends itself to staged construction. This advantage was promoted by the Institute to accommodate these traffic projection differentials.

The Asphalt Institute Laboratory was a major contributor in developing mix designs for various state highway departments to handle the increased traffic loads experienced on the Interstates. Many states adopted the Institute Type IV mixes for their high-traffic pavements.

As the Interstate program moved forward, many significant changes occurred within the industry that enhanced the application of asphalt pavements, and many construction techniques evolved. Institute engineers monitored these developments and incorporated this technology into educational programs for the benefit of the industry.

In the 21st century, our beloved Interstate system faces serious challenges. Basically complete, the system now requires maintenance, rehabilitation, and reconstruction. Lanes are being added and new truck lanes proposed that create added stress to the pavement's structure. Results from the Strategic Highway Research Program (SHRP) of the 1990s are being implemented in the form of Superpave Mix Designs, which also include the use of Performance Graded binders. Today, the Asphalt Institute serves as a significant leader in this ongoing effort of support through its many educational programs, direct engineering assistance, extensive research and laboratory testing efforts.

Not surprisingly, our industry's technological advances over the last several years clearly demonstrate that today's asphalt pavements are far superior to those constructed in the past. Better understanding of design principles, better materials, higher performing binders, and a wide variety of mix types give the engineer the right tools for the best pavement in any situation.

Congratulations to all involved in bringing the Interstate program to where it is today. Your contribution shaped America in many ways and demonstrated the resolve to build a bright future for a grateful nation — one founded on freedom and one that treasures mobility. The Asphalt Institute looks forward to helping shape and build the new vision for our Interstate's next 50 years.

Bernie McCarthy worked with the Asphalt Institute for more than 35 years, served as its vice president before retirement, and still serves as an Asphalt Institute consultant.