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Asphalt Technology News

In This Issue

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

High Polymer Mixes for New and Rehabilitated Pavements

Highly polymer-modified asphalt (HiMA) mixes are showing promise for high-performance pavement applications. By incorporating asphalt binder modified with 7.5 percent styrene-butadiene-styrene (SBS) polymer, HiMA offers increased resistance to fatigue and rutting. Despite the fact that this polymer concentration is approximately three times what is commonly used in polymer-modified asphalt, HiMA mixes maintain ease of production and placement.

Research at the NCAT Pavement Test Track

In 2009, Kraton Polymers sponsored a structural section at the NCAT Pavement Test Track containing HiMA mixes in all three lifts. The high level of polymer modification yields mixes that are very stiff but strain-tolerant, allowing the section to be designed with an 18 percent thinner cross-section. Whereas other comparable structural sections at the track have 7 inches of asphalt, Kraton's section N7 has only 5¾ inches.

This reduction in total asphalt thickness with Kraton's highly polymer-modified mixes is a potential economic benefit for owner agencies, according to Dr. Buzz Powell, NCAT's Assistant Director and Pavement Test Track Manager. "A potential advantage of this technology is the cost to benefit ratio associated with building thinner pavements while achieving comparable performance," says Powell.

Kraton's section N7 is now in its second cycle of trafficking, and pavement performance is still excellent. Over 14½ million ESALs have been applied to date, with minimal rutting and no signs of fatigue cracking. By comparison, the thicker control section has 6 percent cracking in the right wheel path (2 percent total lane width).

The exceptional fatigue and rutting resistance observed in section N7 made HiMA the material of choice in rehabilitating a nearby pavement test section that was completely failed. Oklahoma's section N8 has a soft subgrade representative of native Oklahoma soil. The section was originally constructed in 2006 with 10 inches of asphalt over a stiff soil base, simulating lime stabilization. By the end of the three-year research cycle, the section was in poor condition and received a conventional repair. However, the 5-inch mill-and-inlay failed early in the next research cycle after only 3½ million ESALs.

For the extreme rehabilitation in section N8, 5¾ inches were milled and inlaid with three lifts of HiMA mixes. After approximately 10 million ESALs applied to date, the HiMA repair has outlasted conventional repair by almost 3 times. At the time of rehabilitation, milling was confined within the centerline and edge-line striping of the section. "Due to the high-plasticity clay subgrade, there has been some pumping along the longitudinal joints," says Powell. Areas of transverse cracking have recently occurred along the centerline longitudinal joint, requiring localized patching. However, these issues are not mix-related, and the HiMA pavement is performing well in the remainder of the section, explains Powell.

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Figure 1. Paving on Oklahoma I-40 HiMA Project (photo courtesy of Kraton Polymers LLC)

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Regional Projects

Based on favorable performance of HiMA mixes at the NCAT Pavement Test Track, state agencies are applying this new technology at home. While high-polymer binder is expensive—it can increase mix cost by 15-25 percent when compared to conventional polymer-modified binder—this cost is offset by the potential for pavement thickness reduction and increased pavement lifespan. When pavement thickness is reduced, not only do material costs decrease, but cost is also minimized in sensitive areas where grade changes would incur major expense.

Oklahoma's experience with their rehabilitated section at the track prompted the use of HiMA mixes for a 2012 repair project on I-40 west of Oklahoma City. The 2-mile section plagued with rutting and cracking received 5 inches of milling, 8 inches of HiMA mix and a ¾-inch open-graded friction course (OGFC). Based on data from the NCAT Pavement Test Track, the 8-inch HiMA buildup is expected to perform as well as 10½ inches of conventional asphalt, according to Kenneth Hobson, ODOT Bituminous Engineer. The buildup included a 1½-inch thick, ⅜-inch NMAS rich intermediate layer (RIL) in the first lift. The RIL has increased asphalt content to help resist fatigue and cracking.

HiMA was used to repair a severely rutted section of U.S. 231 in Troy, Alabama, in 2012. Forensic investigations revealed that significant consolidation occurred in the existing SMA binder layer, although the exact cause could not be determined. Four inches of SMA in the north- and southbound truck lanes were planed, replacing them with a 2½-inch layer of HiMA binder course and 1½ inches of traditional PG 76-22 surface course. The night job ran smoothly, and the HiMA mix was found to be easily workable. "It has been a year since we placed the HiMA layer, and ALDOT has continued to monitor the section in Troy using a Profiler," says Chris Huner, ALDOT Assistant Division Engineer. "We have not measured any significant rutting. We are confident that the HiMA product improved the durability and rut-resistance of the pavement."

In the summer of 2013, a city street in Nashville, Tennessee, was also repaired using HiMA. Rutting was a major issue for the Elm Hill Pike project, which included a heavily-trafficked intersection and approximately 1-mile sections on either side. Tennessee DOT provided the specification for the high-polymer material. The 12.5 mm NMAS mix placed in the intersection incorporated PG 76-22E binder and 10 percent RAP. A 9.5 mm NMAS mix with PG 76-28E binder was used for the remainder of the project. "The PG 76-28E binder was very elastic, allowing the 9.5 mm NMAS mix to be placed in a thin lift on the roadway," says Mark Woods, TDOT State Asphalt Materials Engineer.

Projects Around the World

The work at NCAT has captured attention around the world and for a variety of applications. The port of Napier, New Zealand, paved a section of their loading area in 2010, and it still shows minimal rutting and no cracking. Numerous state highway projects in São Paulo and Paraná states in Brazil have included highly modified asphalt trials. So far all are performing well. Other trials include Australia, Italy, Turkey and Qatar.

Using RAP in High Polymer Mixes

A HiMA base mix containing 35 percent RAP was placed in section S5 at the NCAT Pavement Test Track in 2012. This high-RAP focus section, part of the Green Group, was rebuilt in 2013 due to bond failure between the base and intermediate layers. In the rebuild, a heavier tack coat was used, but no changes were made to the original mix design for the HiMA mix.

Laboratory beam fatigue testing per AASHTO T321-07 was performed on plant-produced mix from the original construction to compare the HiMA base mix with the control base mix, also containing 35 percent RAP. The HiMA base mix was produced using Evotherm, while the control base mix contained PG 67-22 binder and was produced using the foaming method. Three specimens of each mix were tested at the following strain levels: 200, 400 and 800 microstrain. According to AASHTO T321, failure is defined as the number of cycles at which initial beam stiffness is reduced by 50 percent.

Figure 2 shows cycles to failure vs. strain level for both mixes. At 800 microstrain, fatigue life was essentially equivalent for both mixes. However, the 35 percent RAP HiMA mix had significantly greater laboratory fatigue life than the 35 percent RAP control mix as strain level decreased. At 200 microstrain, the number of cycles to failure for the HiMA base mix was more than 400 times greater than the control base mix. Using the methodology presented in NCHRP Report 646, the fatigue endurance limit of the HiMA mix was calculated to be 211 microstrain—twice the fatigue endurance limit of the control mix.

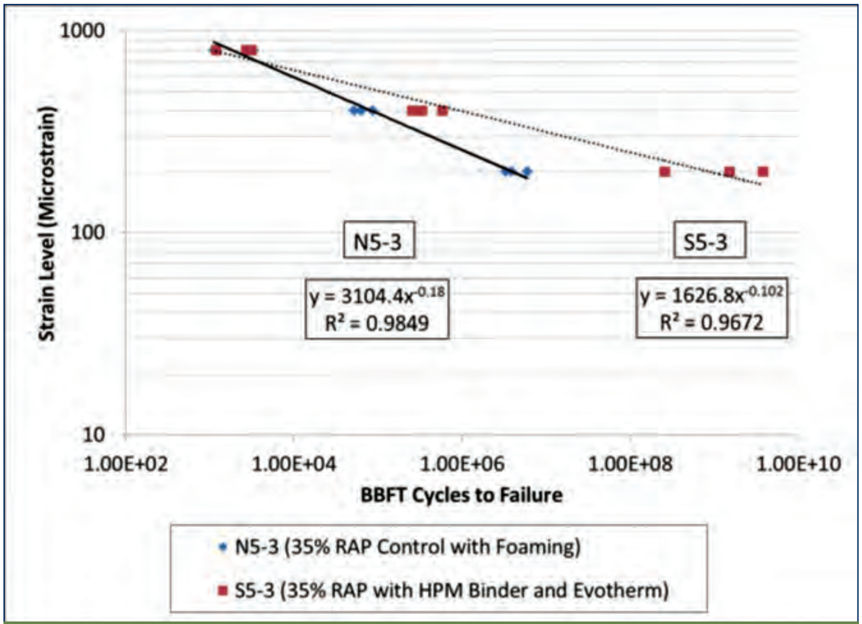

Figure 2. Beam Fatigue Results for 35% RAP HiMA and Control Base Mixes

Debonding of Asphalt Pavement Layers

A strong bond between pavement layers is a critical component in long-lasting asphalt pavements. As a vehicle moves over a pavement, horizontal forces between tires and the pavement surface induce shear stresses at the interface between pavement layers. If the induced shear stress exceeds the bond strength at an interface, debonding may occur. In delaminated areas, the pavement structure no longer acts as a unit. Thus, the critical tensile strain location becomes the debonded interface rather than the bottom of the asphalt pavement, leading to premature failure.

Unfortunately, poor bond between asphalt layers is difficult to identify before surface distresses become visually evident. Loss of bond between upper pavement layers is most often manifest as slippage failures. These crescent-shaped cracks are common in areas where traffic accelerates, decelerates, or turns, inducing high shear stresses. Loss of bond between lower pavement layers results in early fatigue failure, because the pavement no longer acts as a monolithic structure. These pavement distresses require extensive and costly repairs, including full-depth patching or complete reconstruction.

Figure 1. Delaminated pavement layer.

A Closer Look at Bond Failures

Bond failures have occurred in experimental sections at accelerated pavement testing (APT) facilities, giving researchers the opportunity to further investigate this phenomenon. A summary of case studies follows.

Recent Failure of S5 at NCAT Pavement Test Track

Based on measured strain levels and laboratory beam fatigue results, NCAT had high expectations for the high RAP-focused section S5 in the 2012 Pavement Test Track cycle. However, this section, with a 35 percent RAP and highly polymer-modified (HiMA) base mix, was the first section in the Green Group to crack. A forensic investigation revealed that the failure mechanism was actually debonding between the base and binder layer, causing cracking to propagate upward from the bottom of the 50 percent RAP binder layer through the 25 percent RAP SMA surface. Due to the weakened condition of the pavement structure, the base mix also cracked.

"We knew we shot a textbook tack coat at a target rate of 0.05 gallons per square yard of Trackless tack," says Dr. Buzz Powell, NCAT Assistant Director and Test Track Manager. However, visual inspection of the failed areas showed that the binder layer had absorbed tack from the interface. To compound the problem, both base and binder mixes were stiff, with very little natural interlock between them. According to Powell, "We conducted a small laboratory study using actual plant-sampled material from these layers and found the rate needed to be doubled to 0.10 gallons per square yard to optimize the bond strength."

Section S5 was rebuilt using the same HiMA base mix and a few modifications elsewhere, including the increased application rate of Trackless tack. The new binder mix, while still using foamed asphalt, was produced at a higher temperature (325°F rather than 275°F) for optimal mixing of the new and aged binder, and the asphalt content was increased by 0.2 percent.

Section N8 in 2003 Test Track Research Cycle

Section N8 in the 2003 NCAT Pavement Test Track cycle was intended to investigate the ability of a rich-bottom layer to resist fatigue cracking. However, the section experienced early fatigue failure in a fairly localized area, leading researchers to suspect that debonding was to blame. Tack coats had been applied between each lift of the seven-inch cross-section, using PG 67-22 binder at a rate of 0.03 gallons per square yard. Yet trenches cut through the area of severe fatigue cracking confirmed that debonding had occurred at the interface below the SMA surface layer. Cracking was more prevalent in the upper five inches of the pavement than in the rich-bottom layer, and cores revealed that bond strength was greater near the bottom of the pavement than at the top.

FHWA Pavement Test Facility

At the Turner-Fairbank Highway Research Center, the FHWA uses two Accelerated Loading Facility (ALF) machines to apply traffic loading to test pavements at controlled temperatures. Each ALF machine operates at a wheel speed of up to 11 mph and features variable wheel loading, with interchangeable tire configurations and programmable lateral wander. The Pavement Test Facility has 12 full-scale pavement lanes, each of which can be subdivided into four test sites.

A recently completed research project evaluated the performance of both modified and unmodified asphalt binders. Each dense-graded 12.5 mm NMAS mix was placed in two lifts on the same day, and no tack coat was used. Seven lanes had a total asphalt thickness of 100 mm, while the rest had 150 mm. All sections were loaded to failure. Of the 12 sections, only one—the 150 mm unmodified PG 70-22 section—experienced delamination, but there was no indication of debonding until cores were cut at the end of the project. Interestingly, the delaminated area did not

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extend throughout the entire test lane, only the portion that was tested at 19°C. No debonding was observed in the other sites within the lane, which were tested at 64°C and 74°C for rutting and again at 19°C in an aged condition.

Existing Surface Type	Residual Application Rate (gallons/sy)
New Asphalt	0.035
Old Asphalt	0.055
Milled Asphalt	0.055
Portland Cement Concrete	0.045

Table 1. NCHRP 9-40 Recommended Tack Coat Application Rates

Cores from the other test lanes were evaluated for bond strength using Kansas DOT test method KT-78. "This is a direct tension test, which we chose because we could easily implement the test method using the Asphalt Mixture Performance Tester (AMPT)," says Nelson Gibson, a research civil engineer with FHWA. In each case, the bond strength was found to be greater than that of the mix itself, as none of the samples failed at the layer interface. Gibson says bond strength will be tested immediately after construction during the next research project at the FHWA Pavement Test Facility.

Using Tack Coats to Prevent Bond Failures

Tack coats are used to create a good bond between asphalt pavement layers, thus transferring shear stresses throughout the pavement cross-section. While some states do not require tack coats, many consider it essential. For example, Heavy Vehicle Simulator (HVS) testing at the University of California Pavement Research Center in the 1990s showed that a weak bond between asphalt layers that were not tacked significantly impaired performance. Caltrans later began specifying tack coats. Appropriate selection of tack coat material and application rate, as well as uniformity of coverage, are necessary to ensure adequate bond strength.

Tack coats are typically asphalt emulsions or paving grade asphalt binders. Emulsions are often used because they spray more easily, making uniform application easier to achieve. Polymer-modified tack coat materials are sometimes used in high-stress applications for increased strength and durability. Another material choice is Trackless tack, a proprietary emulsion that sets quickly, preventing the loss of material by tire pickup from construction traffic and thus improving bond.

The texture of the underlying surface plays a role in achieving a good bond. NCHRP 9-40 found that milled surfaces improve shear strength. An appropriate tack application rate should be selected based on the condition of the underlying surface. As shown in Table 1, a higher application rate is needed on milled surfaces and existing pavement than between two new layers, due to increased surface area. While too little tack inhibits a good bond, too much also has a negative effect on bond strength by acting as a lubricant and creating a slip plane between layers.

Uniformity of coverage is also a key consideration for successful tack coat application. Uneven streaks or puddles of tack material should be avoided in order to facilitate optimum bonding. Non-uniform tack coverage can be the result of clogged nozzles on the distributor, and the height of the spray bar should also be properly adjusted to provide double lap or triple lap coverage. Tire pickup should be minimized by keeping equipment off the tacked surface as much as possible until the tack material has set. Dust, dirt, or moisture on the existing surface should be avoided as well.

Although tack has traditionally been applied using a distributor, spray pavers are also used to apply tack immediately prior to spreading the mix. This specialized equipment eliminates the possibility of tire pickup, allowing for uniform tack application and an improved bond. During the 2009 research cycle at the NCAT Pavement Test Track, a spray paver was used in Florida's open-graded friction course (OGFC) evaluation. Section N1 incorporated a heavier polymer-modified tack coat applied using a spray paver, while section N2 used trackless tack applied at a typical rate with a distributor. The heavier tack coat applied with a spray paver was shown to improve cracking resistance in the OGFC, but the tack filled some of the OGFC void space and reduced its drainage capacity in heavy rains. A spray paver was also used in 2012 to place an ultra-thin bonded surface course on section 22 of NCAT's current Lee Road 159 preservation treatment experiment.

Figure 2. Spray paver used in construction of section 22 on Lee Road 159

Quantifying Bond Strength

Bond strength between pavement layers can be quantified using destructive testing, such as the bond strength test developed at NCAT in a study funded by the Alabama Department of

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Transportation (ALDOT). This method, which has been adopted as ALDOT Procedure 430, shares some similarities to bond strength tests used in Europe and some states, including Florida and West Virginia. In this procedure, cores are placed in a bond strength loading frame, and the layers are sheared apart using the Marshall load frame apparatus at a loading rate of two inches per minute. Interface bond strength is then calculated by dividing the maximum shear load by the cross-sectional area of the core.

Figure 3. Heavy polymer-modified tack coat applied prior to OGFC using spray paver (photo courtesy of FDOT)

The ALDOT study included a field investigation of pavements exhibiting both good performance and premature failure. Cores were taken at five sites that had been in service for more than four years and showed no signs of debonding. These pavements had been constructed with asphalt emulsion and asphalt binder tack coats placed on new and milled asphalt surfaces, as well as old Portland cement concrete. The average bond strengths for these five sites were all greater than 100 psi. Nine pavement sections with slippage failures were also examined. Cores were extracted in the delaminated areas and from intact areas nearby. Average bond strengths for the intact areas were all in excess of 87 psi. In the areas with slippage failures, some specimens broke during coring, and the remainder of the cores from the failed areas had bond strengths ranging from approximately 25 to 60 psi. Based on these results, a preliminary bond strength requirement of 100 psi, tested according to the ALDOT-430 procedure, was recommended for evaluation of the interface bond between the surface and underlying layers.

West Virginia recently implemented bond strength testing in their specifications after experiencing delaminations on interstate highways—including a severe failure that required an emergency repair project during the winter. "Although tack was required, we just weren't getting the results we wanted," says Aaron Gillispie, West Virginia Division of Highways State Materials Engineer. "We looked at different bond strength tests using torsion, tension and shear, and decided to go with shear testing using the Marshall stabilometer." This year, bond strength testing will be conducted on cores from nine interstate projects. Gillispie says they are primarily gathering data to evaluate the preliminary requirement of 100 psi. However, four of the projects do not include a separate pay item for tack coat, and for those projects, penalties will be assessed for bond strengths less than 100 psi only if the contractor chooses not to apply tack. According to Gillispie, "Our traditional prescriptive emphasis on specifying tack resulted in insufficient, inconsistent tack and several post-construction debonding failures. But our new specifications target the final product—what we really want is bond performance in the constructed mat."

NDT for Detecting Delamination

Project R06(D) of the second Strategic Highway Research Program (SHRP II) investigated nondestructive testing (NDT) methods that potentially could be used to identify delamination between asphalt layers before surface distresses appear. Agencies need a rapid NDT method that can identify and quantify delaminations following construction or as part of a pavement management system so that repair or rehabilitation can be considered before pavement distress occurs. Originally, the project goal was to find a technology capable of testing an entire lane width in a single pass at safe operating speeds, but the scope was broadened in order to examine more of the available technologies.

Several NDT methods were included in a field evaluation at the NCAT Pavement Test Track, where sections intentionally constructed with and without delaminated areas were built in the non-trafficked inside lane. The NDT technologies included ground penetrating radar (GPR), infrared thermography, mechanical wave methods and deflection measurement methods. Two technologies were selected for further evaluation—a GPR unit with a multiple-antenna array (manufactured by 3-D Radar) and a mechanical wave technology with a traveling point-load system (developed by Olson Engineering). Each vendor developed equipment and software improvements prior to evaluation in uncontrolled field conditions at sites in Maine, Kansas and Florida.

The multi-antenna GPR unit is capable of testing full-lane width while operating at moderate traveling speed. This method is capable of identifying pavement variations and determining the depth of a discontinuity. However, delaminations between asphalt layers could only be detected when moisture was present in the debonded area.

The mechanical wave system operates at walking speed and measures both impact echo (IE) and spectral analysis of surface waves (SASW). IE is capable of identifying delamination more than four inches below the surface when the pavement is cool and stiff. SASW can identify discontinuities within seven inches of the surface when there is a significant change in stiffness. Neither measurement can determine pavement condition below a discontinuity.

These NDT technologies can be useful tools in project-level assessments. With further improvements in data analysis software, the technologies could also be used in network-level pavement evaluations. While these NDT methods can identify pavement discontinuities, coring must still be used to conclusively determine the cause of the discontinuity.

Improving RAP Mix Durability

Using reclaimed asphalt pavement (RAP) in asphalt mixes reduces cost by decreasing virgin asphalt binder and aggregate. Recent increases in asphalt binder cost have spurred interest in using higher percentages of RAP in asphalt mixes. However, because RAP binder is aged and therefore stiffer and less strain-tolerant than virgin binder, high-RAP content mixes are perceived as being more susceptible to cracking. Thus, agencies have typically limited the amount of RAP allowed in asphalt mixes based on long-term performance concerns.

Field studies, however, have shown that mixes with more than 25 percent RAP can perform well if they meet standard mix design and quality assurance criteria. These studies include a long-term performance comparison of overlays with virgin and 30 percent RAP mixes as well as test sections on the NCAT Pavement Test Track with up to 50 percent RAP. Based on these favorable field performance studies, agencies are gaining confidence with the use of higher RAP contents. Contractors are also learning how to manage RAP to minimize dust content, contamination and variability within their stockpiles. Across the U.S., average RAP contents continue to rise.

The most common method for improving the durability of high-RAP mixes is to use a softer virgin binder grade. Currently, AASHTO M 323 recommends changing the binder grade for RAP contents greater than 15 percent. When the RAP content is between 15 and 25 percent, the virgin binder should be one performance grade lower than normal. At RAP contents greater than 25 percent, blending equations, which require additional testing, should be used to determine the virgin binder performance grade.

Research also suggests that RAP mix performance can be enhanced by increasing the volume of virgin binder. Another potential means of improving high-RAP mix durability is the use of warm-mix asphalt (WMA) technology, as seen in results from the fourth research cycle at the NCAT Pavement Test Track.

NCAT recently evaluated these three options—using a softer virgin binder grade, increasing the effective virgin binder volume, and using warm-mix technology—to assess their effectiveness in improving the durability of RAP mixes. Three 12.5 mm NMAS mixes were designed using 10, 25, and 50 percent RAP and PG 67-22 binder. In order to achieve satisfactory volumetrics, the RAP was fractionated over the #4 sieve for the 50 percent RAP design, but the 10 and 25 percent RAP mixes contained unfractionated RAP. Experimental mixes at all three RAP contents included PG 58-28, PG 67-22 at 0.25 percent and 0.5 percent higher asphalt contents, and PG 67-22 with a chemical warm-mix additive (Evotherm 3G™). Mixing and compaction temperatures were 20-25°F lower for the WMA mixes.

Laboratory testing included linear amplitude sweep (LAS) testing to assess fatigue life of the blended virgin and extracted RAP binders, energy ratio (ER) to evaluate top-down cracking resistance, and the overlay tester (OT) to assess resistance to reflective cracking. The Asphalt Pavement Analyzer (APA) was also used to evaluate rutting potential.

Results and Conclusions

LAS testing predicts binder fatigue life at a given strain level using the Dynamic Shear Rheometer. The procedure applies cyclical loading with increasing load amplitude and measures the number of cycles to failure. For this study, the blended binders for each of the mix designs were tested at 2.5 and 5.0 percent strain. As expected, the LAS results showed that number of cycles to failure decreased as strain level increased. The results also showed a decrease in expected fatigue life for RAP and PG 67-22 blends compared to all-virgin PG 67-22 binder. However, the RAP/PG 58-28 blends showed greater fatigue lives than the RAP/PG 67-22 blends. Increasing the virgin binder content had little effect on the LAS results. While using the WMA additive had a greater effect on increasing the fatigue life of the blended binder at higher RAP contents, the positive effect was still slight. The LAS results indicated that using a softer binder was the most effective means of increasing binder fatigue life.

Fracture Energy (FE) determined from indirect tensile testing was shown to be related to fatigue performance at WesTrack, but there are no generally accepted minimum criteria. In this evaluation, FE results were mixed. For 10 and 50 percent RAP mixes, FE was improved by using a softer binder, increasing the virgin binder content, and using WMA. But for the 25 percent RAP mixes, the PG 67-22 mix at optimum asphalt content had the highest FE value.

The energy ratio (ER) procedure was developed in Florida to assess the potential for top-down cracking based on results from indirect tensile resilient modulus, creep compliance, and fracture energy (FE) testing. Higher ER values indicate greater resistance to top-down cracking. For both 10 and 50 percent RAP mixes, the greatest ER increase occurred with the WMA mixes and with increasing the virgin binder content by 0.5 percent. Using 0.25 percent higher virgin binder content and a softer binder also increased the ER, but to a lesser degree, for both 10 and 50 percent RAP mixes. For the 25 percent RAP mixes, ER decreased with using additional virgin asphalt, a softer binder and WMA. However, all of the 25 percent RAP mixes had an ER value greater than 2.0.

The overlay tester (OT) was used to evaluate resistance to reflective cracking. Based on previous high-RAP studies at NCAT, the maximum crack displacement was set at 0.013 inches rather than the typically prescribed 0.025 inches. Extremely high strains occur during OT evaluations. Because the conditions are so harsh, the number of cycles to failure decreased dramatically with the addition of more than 10 percent RAP in the mixes containing PG 67-22 at optimum asphalt content. Due to high variability in the test results, none of the options for improving durability showed

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a statistical improvement in OT results at any of the RAP contents. However, numerical improvements in OT results were observed. At 10 percent RAP, an additional 0.25 percent virgin binder showed the greatest increase in cycles to failure, followed by using WMA. At 25 percent RAP, using a softer binder, WMA, and increasing the virgin binder content improved OT results, but only slightly. Finally, at 50 percent RAP, using a softer binder and increasing virgin binder content showed increased OT performance.

At 10 percent RAP, statistical analysis of the APA results indicate that using a softer binder could increase susceptibility to rutting. However, based on the APA results, none of the 25 and 50 percent RAP mixes should be susceptible to rutting.

Recommendations

Based on the results of this limited laboratory study, the following recommendations are given:

- For mixes with less than 25 percent RAP, increasing the virgin binder content by 0.5 percent or using WMA technology should increase durability.
- At 25 percent RAP, durability may be improved by using a softer binder or WMA technology.
- For 50 percent RAP mixes, increasing the virgin binder content by 0.5 percent or using a softer binder should improve durability.

When using these options to increase durability, mixes should be thoroughly tested to ensure that resistance to rutting is not compromised. Field validation of these options is needed, and it should be noted that mix performance may be different based on type of WMA technology used. Cost analyses should also be performed to determine the most cost-effective solution when different options could result in similar performance.

Asphalt Forum

NCAT invites your comments and questions, which may be submitted to Courtney Jones at **courtneyj@centurytel.net.** Questions and responses are published in each issue of *Asphalt Technology News* with editing for consistency and space limitations.

Chris Abadie, Louisiana DOTD

For mix designs, the specific gravity of fine aggregate is verified by our district labs. Does your state or agency:

1. Assign a statewide value to each aggregate source for +4 or -4 material?
2. Require the contractor to report the specific gravity of each individual component and verify?
3. Other?

Michael Heitzman, NCAT

States with abundant supplies of high quality, polish-resistant aggregate have little trouble managing asphalt pavement surface friction. States with few or no in-state friction aggregate sources must place more emphasis on the quality and quantity of friction aggregate in their asphalt mixture design specifications. If you are a friction aggregate-poor state, how do you specify the quantity of friction aggregate in asphalt surface mixtures?

Kenneth Hobson, Oklahoma DOT

Raveling occurred on some projects where a check of G_{sb} from field stockpiles indicated a significant difference from what was reported on the mix design. The change in G_{sb} can be related to G_{se} normally during production. If the difference ($G_{se} – G_{sb}$) is not similar to actual field differences, standard G_{sb} correction methods based on changes in G_{se} are not appropriate. Lower G_{sb} would result in lower VMA and lower effective binder content ultimately. A round robin testing program between 17 labs was conducted. The absorption values for the fine aggregate ranged from 0.6 to 3 percent. The absorption standard deviation was nearly three times the value in AASHTO T 84, Table 1. The standard deviation for bulk specific gravity was nearly double the value in T 84. A historical database comparison of a computed G_{sb} to the mix design G_{sb} is being performed.

Round robin Hamburg rut testing has shown high variability in single and multiple lab test results. A modification of AASHTO T 312 in a small experiment has shown that we may be able to reduce some variability. A more extensive experiment to validate the improvement is planned.

Asphalt binder with liquid anti-stripping agents (ASA's) may drop the upper temperature in the Performance Grade of the binder. Poly-phosphoric acid may cause a more significant drop in PG grade for some binders with some ASA's.

Mark Woods, Tennessee DOT

Do any states have specifications requiring paver tunnel extensions? What advantages/disadvantages have you observed from having/not having this spec?

Asphalt Forum Responses

The following responses have been received to questions shared in the Spring 2013 Asphalt Forum.

1. Does anyone have special considerations in their mix design requirements for high water absorption (2-4 percent) aggregates? (Joe Schroer, Missouri DOT)

Michael Stanford, Colorado DOT

No. High water absorption aggregates are not typical in Colorado.

Greg Sholar, Florida DOT

FDOT requires that plant-sampled mix be conditioned in an oven at compaction temperature for one hour prior to testing for G_{mm} and G_{mb}. A study was done to warrant this change to allow asphalt to absorb in the soft Florida limestones. The one-hour conditioning is to represent an average haul time. In addition, the real G_{sb} of coarse and fine aggregates is determined and not estimated based on G_{se} for the determination of VMA.

Chris Abadie, Louisiana DOTD

Louisiana requires longer aging (one or two hours more) of gyratory samples when water absorption of a mixture is higher than 2 percent.

Kevin Kennedy, Michigan DOT

Michigan does not have any special requirements.

James Williams, Mississippi DOT

MDOT does not currently make any type of special consideration for high water absorption of aggregates during the design process.

Charlie Pan, Nevada DOT

We use higher viscosity binder or polymer modified asphalt.

Denis Boisvert, New Hampshire DOT

No.

Eric Biehl, Ohio DOT

Ohio DOT uses the SSD procedure for determining maximum specific gravity (G_{mm}) for high water absorption aggregates.

Kenneth Hobson, Oklahoma DOT

We age the mix design mixtures from two to four hours at 300°F. Normally, we age these materials at 300°F for two hours if absorption is less than one percent. We compact at 300°F.

2. Where does your agency take asphalt mix samples for QA (out of truck? auger? behind paver?), and why do you take them at this location? (Ray Brown, NCAT)

Michael Stanford, Colorado DOT

CDOT allows for samples to be taken from points of manufacture, storage and delivery. This includes sampling from the windrow, augers and behind the paver.

Greg Sholar, Florida DOT

FDOT currently obtains the QA samples from the truck at the asphalt plant (same location as QC sample).

Chris Abadie, Louisiana DOTD

Louisiana presently takes asphalt samples from the back of the truck at the plant, prior to delivery to the DOTD project. Cores are taken at the roadway.

Kevin Kennedy, Michigan DOT

Michigan samples behind the paver, because it is considered most representative of the mix being placed.

James Williams, Mississippi DOT

Samples for QA are taken out of the truck prior to the truck leaving the asphalt plant. This mirrors the process used by contractor QC. The samples are taken in this manner because it provides a sample point at a particular plant production tonnage.

Charlie Pan, Nevada DOT

We sample behind the paver, which represents the material that has actually been laid down.

Denis Boisvert, New Hampshire DOT

NHDOT samples behind the paver to test the final received product. This sample location is the only way to capture segregation problems. Additionally, we require that the contractor take the sample to eliminate the initial question resulting from a poor test result: Was it sampled correctly?

Eric Biehl, Ohio DOT

Ohio DOT can take samples from all the above. Most samples are taken from the truck at the mix plant, though.

Kenneth Hobson, Oklahoma DOT

Our standard practice is to sample from the truck to control the plant and for pay factor determinations. We do allow sampling behind the paver should segregation occur but that is rare. This data is not used for pay. Some have sampled from the drum discharge according to AASHTO T 168 (ASTM D979) section 5.3.2. Care must be taken to get the full stream of material. An automated device at this location would ensure a more representative sample and enhance safety.

Seyed Tabib, Ontario Ministry of Transportation

In Ontario, the QA samples are taken on the paving site either at the MTV, or at the paver auger or behind the paver (but not from the truck). The reason is that these samples need to be taken and sealed in the presence of the Contract Administrator and be sent

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to the QA lab for acceptance testing.

Cliff Selkinghaus, South Carolina DOT

We have the contractors obtain the samples from the hauling trucks. We feel like taking the samples from the truck minimizes the time necessary to obtain QC/QA tests and make plant adjustments; also, it is helpful to have the field lab and testing equipment nearby to minimize reheating time, especially when making gyratory specimens.

Mark Woods, Tennessee DOT

Samples are typically taken from trucks at the plant simply because this is the easiest place to do so in terms of personnel and logistics.

3. Has anyone conducted a comparison between plant and roadway sampling and testing variability? If so, is a report available? (Don Watson, NCAT)

Chris Abadie, Louisiana DOTD

Dr. Mohammad of the Louisiana Transportation Research Center (LTRC) is conducting an NCHRP study that should include a comparison of this type. LTRC has individual studies that have compared this, but this objective was not the primary reason for the research and therefore the data is not readily available.

4. Does your agency have data or reports that document the effect of existing pavement condition and surface preparation on thin overlay performance? Is there any explanation for the wide range in performance of thin asphalt overlays? (Don Watson, NCAT)

Michael Stanford, Colorado DOT

No. We have typically found that the wide range in overlay performance has been caused by a combination of factors, including existing pavement condition, selection of overlay type and contractor experience.

Chris Abadie, Louisiana DOTD

Louisiana data in this area is limited. We do have records of IRI before and after the application of thin lifts, but we have no quantification of project-specific pavement condition and surface preparation.

Kenneth Hobson, Oklahoma DOT

We have no reports of existing pavement condition other than our pavement management system data.

Specification Corner

Colorado

CDOT has revised our recycled asphalt pavement (RAP) specification. The allowable RAP amount in HMA will now be determined by the percentage of binder replaced, instead of being based on total mass. The revised specification allows for a maximum binder replacement of 23 percent for all lifts.

Florida

Effective July 1, 2013, FDOT made some significant binder changes. The first change is related to asphalt rubber binders. FDOT is eliminating two asphalt rubber binders (ARB-5 for dense graded mixtures and ARB-12 for OGFC mixtures) and replacing both of them with PG 76-22 (ARB), which must meet all of the same Superpave binder requirements as FDOT's polymer modified PG 76-22 (PMA), except that the solubility requirement is waived. Additionally, a separation requirement is added; after testing per ASTM D7173, the maximum difference in softening point values for the two sample portions is set at 15°F. A minimum of 7 percent ambient or cryogenically ground rubber must be used. In addition, polymers may be used if necessary to meet the specification requirements. The second binder change implements the Multiple Stress Creep Recovery (MSCR) requirements of J_{nr} and % recovery. PG 76-22 (ARB) and PG 76-22 (PMA) binders will be tested at 67°C and must meet the J_{nr} requirements of a "V" grade and must have a % recovery value above "the curve" from AASHTO TP 70. Third, polyphosphoric acid may be used as a modifier in PMA binders, provided that the polyphosphoric acid does not exceed 1.25 percent by weight of asphalt binder.

Georgia

GDOT recently performed an in-house study of numerous RAP stockpiles around Georgia. For this study, GDOT heated sized virgin aggregate above normal mixing temperatures and combined it with unheated RAP in a pugmill. The goal was to determine how much mass of AC would transfer to the virgin aggregate in a more real-world scenario. We noticed only occasional scuffing of the virgin material without any appreciable mass transfer or coating.

GDOT then oven-heated samples of stockpiled RAP to observe the consistency and coating of the RAP aggregate. The AC was then removed from the samples in the ignition oven. Virgin AC was added back to the RAP aggregate in increments of 0.25 percent until the original consistency and coating was achieved. The difference between the initial and recoated RAP AC percentages was calculated as the effective AC ratio in order to determine how much of the RAP AC was contributing to the effective AC content and AC film thickness. GDOT eventually settled on an average ratio of 75 percent, meaning that 75 percent of the AC in RAP was contributing to the effective AC in the mix. Minimum film thickness was set to 7 microns.

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This led GDOT to develop the Corrected Optimum Asphalt Content (COAC) for asphalt mix designs. The COAC reflects the Original Optimum Asphalt Content (OOAC) plus the addition of virgin AC in the amount of 25 percent of the RAP AC contribution. The COAC is typically used in production. This RAP binder adjustment with COAC method was just included in our newly published spec book (2013), Section 828 – Hot Mix Asphaltic Concrete Mixtures.

Louisiana

LADOTD is increasing the minimum VFA for design to 72 percent in an attempt to increase the film thicknesses in mixtures. For crumb rubber modified mixes, the minimum VFA will be 75 percent. Five pilot projects indicate that this can be achieved and will be required in the next Standard specification for HMA.

Michigan

We have changed our RAP specification to allow for increased usage of RAP and have developed a permissive specification allowing the use of recycled asphalt shingles. We have also developed a permissive specification allowing increased usage of warm mix asphalt in support of FHWA's Every Day Counts Initiative.

Mississippi

Mississippi has increased the amount of RAP content in surface lifts from 15 percent to 20 percent maximum. This was done for economic benefits for the contractor and agency. Recent studies have shown that use of increased amounts of RAP can be done successfully.

A specific gravity correction for asphalt mixture has also been written into specifications. Asphalt mixtures with high maximum theoretical aggregate specific gravities will have a pay adjustment applied.

Mississippi is also considering the following changes:

1. Revising current crumb rubber specification to include 30-40 mesh material versus the current 80 mesh requirement.

2. Developing a specification around the use of shingles in asphalt mixtures.

3. Developing a specification around the use of limited amounts of RAP in SMA mixtures.

New Hampshire

June 2011: Allowed for Warm Mix Asphalt by adopting the NEAUPG qualification process. Minimum mix production and placement temperatures were reduced to accommodate these technologies.

Dec. 2011: Expanded the paver equipment requirements to apply to method work, as well as QC/QA. The text had been created during the adoption of Superpave but was not located in the general section. Also required that high-strength mix be produced under QC/QA specifications for quantities over 2000 tons. The DOT felt that there was ample track record with this material to be able to meet consistency requirements.

Jan. 2012: Required that Material Transfer Vehicles be capable of re-mixing. Some early units only conveyed material. Observations with infrared imaging indicated that re-mixing eliminated temperature segregation. Re-mixing also addresses particle segregation.

Oct. 2012: Leveling courses and the first layer over a gravel or stone base, milled surface or an existing surface, shall be excluded from thickness requirements due to the irregularities in the milled or delaminated surface.

Dec. 2012: Added a specification table for tack grades RS-1, RS-1h, CRS-1 and CRS-1h. There is interest in reducing tracking of tack; Vermont requires RS-1h, which was creating storage issues for border asphalt plants. Our specification generally referred to AASHTO M 140, which refers to ASTM D 977, and does not include these "h" grades, while including many grades we do not care to use.

Jan. 2013: Softened the two-year old 10 percent density penalty for method specification work. Contractors found it harsh for roadways that were out of shape, particularly when leveling was performed by DOT forces. A graduated penalty replaced it, such that density results for 1-in. overlays below 91 percent but equal to or greater than 90 percent will be assessed a 5 percent reduction, and for any results below 90 percent, a 10 percent penalty will be assessed for all tonnage placed. Noncompliant material below 90 percent may be removed at no payment for the material or its removal.

Jan. 2013: Echelon paving is allowed as a substitution for joint adhesive. The technique is considered an upgrade for the specified material, which will still be paid for as compensation for the cost of the echelon paving.

Ohio

OhDOT added a highly polymerized PG 88-22M for high-stress areas, possible pavement thickness reductions, and other applications.

Oklahoma

A RAP/RAS Special Provision based on binder replacement will be written. We would like to get two projects constructed this fall with RAS.

In 2012, we implemented a Special Provision to increase binder content by raising VMA limits by 0.5 percent and lowering SGC gyrations. There are a few more Hamburg rut test failures this year. This was expected but the trade-off resulted in better compaction in the field and seems to be working well. This also made designing by binder type rather than ESALs, potentially reducing the total number of mix designs for a project by 30 percent. **http://www.odot.org/c_manuals/specprov2009/oe_sp_2009-708-26.pdf**

Ontario

MTO recently implemented a specification that covers measurement, acceptance and payment for hot mix courses (multi-lift) when the unit of measurement for payment of the hot mix is "square metres." It also covers the measurement and acceptance of pavement width and thickness.

NCAT Evaluates Safety Edge$_{SM}$ at Pavement Test Track

Pavement shoulder edge drop-offs have been recognized as roadway safety hazards for decades. Studies conducted by various organizations, including TRB and AAA, have shown that crashes in which pavement edge drop-offs are a contributing factor are not limited to road construction sites, but also occur frequently on rural and secondary roads where shoulders are non-existent or worn away. Between 2002 and 2004, Missouri reported that pavement edge drop-offs were a contributing factor in up to 24 percent of rural run-off-road crashes on paved roads that had unpaved shoulders.

Safety Edge$_{SM}$ Advantages

- Saves Lives
- Increases edge durability
- Low cost

Safety Edge$_{SM}$ is all about saving lives by helping prevent crashes related to pavement edge drop-offs. Safety Edge$_{SM}$ is an innovative asphalt paving technology where the interface between the roadway and graded shoulder is paved at an optimal angle to mitigate vertical drop-off, thereby improving safety. The desired angle of 30 degrees is attained by outfitting an asphalt screed with a device that extrudes the pavement edge as the paver passes. This process is intended to mitigate shoulder pavement edge drop-offs during the construction process in a manner that is sustained over the life of the pavement. In addition to improving safety, research at the NCAT Pavement Test Track has confirmed that mat compaction near the edge of the pavement is also enhanced. As seen from construction quantities at the Track, very little additional material is required; thus, Safety Edge$_{SM}$ technology has the potential to improve safety and performance at little or no extra cost.

Because Safety Edge$_{SM}$ is a proven roadway departure prevention technology, the Federal Highway Administration (FHWA) is accelerating deployment through the Every Day Counts Initiative. Currently, more than forty state DOTs and all three FHWA Federal Lands Divisions have adopted the Safety Edge$_{SM}$ as a standard construction practice with a written policy and specification. Another goal is expanding the use of Safety Edge$_{SM}$ by local agencies.

Figure 1. Trial mixes placed with and without Safety Edge$_{SM}$ at the NCAT Pavement Test Track

FHWA has contracted with NCAT to conduct research regarding field constructability concerns raised by industry and agency personnel. For example, the angle used for Safety Edge$_{SM}$ paving may need to vary to optimize effectiveness with regional mixes (e.g., those that tend to exhibit tender behavior and often steepen during rolling operations) to ensure the final angle approximates the desired slope of 30 degrees. Of course, the final angle is expected to have an impact on vehicle recovery over the life of the pavement, when the edge becomes exposed. The impact on implementation success of performance specifications versus a qualified products list (QPL) could also be considered. It may be easier to obtain support from the paving community if contractors are free to innovate to meet new specifications using their own resources.

NCAT is in a unique position to build upon FHWA's past successes with Safety Edge$_{SM}$ implementation and help accelerate the adoption process for state DOTs. Reconstruction of the NCAT Pavement Test Track in the summer of 2012 provided an excellent opportunity to objectively evaluate the impact of Safety Edge$_{SM}$ technology on mix quantities, pavement performance and vehicle recovery. Including Safety Edge$_{SM}$ in the fifth research cycle of the NCAT Pavement Test Track was also intended to facilitate comparing angle of attack during paving with final angle after compaction for a variety of mixes and layer thicknesses, creating test sections in which the dynamics of vehicle recovery could be comprehensively studied in order to optimize overall safety. Another research goal was to determine if extra compaction and edge durability were provided by using Safety Edge$_{SM}$.

NCAT's work plan to help FHWA meet its implementation objectives consists of six tasks, half of which were completed in the summer of 2012. In the first task, three different commercially available Safety Edge$_{SM}$ devices—offered by Advant-Edge, Transtech and Carlson—were mounted and evaluated in the initial days of Track reconstruction when practice mixes were being produced, tested and placed in the open lot on the northeast corner of the property. None of the devices were observed to produce pavement edge angles that were sensitive to mix properties for the range of mixes placed in the summer of 2012. In the second task, the Carlson device was selected for placing mixes on the Track for two reasons. Most importantly, it was the easiest device to engage/disengage while the paver was in motion to facilitate building test sections with and without a treated edge. Secondly, the Carlson device was the only one not mounted on the inside of the screed. Devices mounted inside the screed were found to interfere with auger extensions and prevent the screed

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Figure 2. Paving porous friction course on the Track with Safety Edge$_{SM}$

extension from being fully retracted. Track paving required a full range of motion with hydraulic screed extensions within the limits allowed by the auger extensions to facilitate maneuverability while paving base layer mix through instrumentation arrays. The Safety Edge$_{SM}$ technology was employed in each asphalt pavement layer in order to study mat density in all layers and to evaluate vehicle runoff recovery with multiple pavement edge drop-off heights. The paving crew reported they liked the Carlson device, noting it would be very useful for paving crossovers, turnouts and driveways because it was so easy to engage/disengage.

In the third task, differences resulting from engagement of the Safety Edge$_{SM}$ device were quantified. Specifically, density near the edge of the mat and required placement tonnage were the focus of the investigation. Slices were cut from the edge of mat sections built with and without the Safety Edge$_{SM}$ deployed on all three lifts of asphalt pavement placed on top of dense crushed granite base. Design layer thicknesses for the dense graded asphalt (DGA) base layer, DGA intermediate layer and stone matrix asphalt (SMA) surface layer were 2½ inches, 2¼ inches and 1¼ inches, respectively. Mat edge slices were carefully measured, then separated by layer and cut into blocks. The bulk density of each block (within each layer) was then measured to calculate mat density. With geometry and mat density measured, the total difference in tonnage could then be calculated. The density in the wedge at the edge of the mat was over one percent higher in the DGA base layer, almost 4 percent higher in the DGA intermediate layer and almost 7 percent higher in the SMA surface layer. Mat densities in the SMA surface outside of the wedge were approximately 1-2 percent higher, and no differences exceeded 1 percent for the DGA base and intermediate layer outside of the wedge. Although deployment of the Safety Edge$_{SM}$ device resulted in higher mat densities and tapered geometries, the estimated increase in mix tonnage was less than a tenth of a percent.

The objective of the fourth task was to quantify the impact of the Safety Edge$_{SM}$ on vehicle runoff and recovery. After construction was complete, but before fleet operations initiated, an instrumented passenger vehicle was run off, then back onto the Track over a range of speeds and edge drop-off heights. High-speed dynamic data was collected as maneuvers were executed to precisely document the vehicle's behavior during runoff and recovery. This data is being subjected to a modeling process that will predict runoff and recovery, both with and without Safety Edge$_{SM}$, for any angle and height condition.

The focus of the fifth task is to communicate NCAT's ongoing experiences with Safety Edge$_{SM}$ technology to the paving community. This will involve the preparation and dissemination of several articles, an overview presentation and an informational video. Future articles will present the outcome of vehicle recovery testing and long term performance at the edge of the mat, which is the focus of the sixth and final task.


Figure 3. Cutting mat edge slices for density determination

NCAT's experience with Safety Edge$_{SM}$ during construction, dynamic vehicle recovery measurements after construction, and performance assessments as a function of traffic will produce objective data to answer practical questions generated by contractors and agencies. This research will help accelerate FHWA's implementation of Safety Edge$_{SM}$ technology into mainstream paving practice in the US.

New Recommendations for Calculating Salvage Value in Life-Cycle Cost Analysis

Life-cycle cost analysis (LCCA) is a commonly used means of comparing two or more investment alternatives. Most highway agencies consider LCCA in selecting between an asphalt pavement and a concrete pavement on major projects. There are several critical assumptions that have to be made in conducting an LCCA. How agencies make these assumptions can easily tilt the outcome of an LCCA to favor one pavement type.

An LCCA includes initial costs and future costs that are expected to occur over a long period of time (i.e. the Analysis Period) to determine the best long-term value among available options. Life-cycle costs are most commonly calculated in terms of Net Present Value (NPV), which includes lifetime expenditures for a paving

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project—initial construction, rehabilitation and maintenance—as well as the salvage value at the end of the Analysis Period (Figure 1).

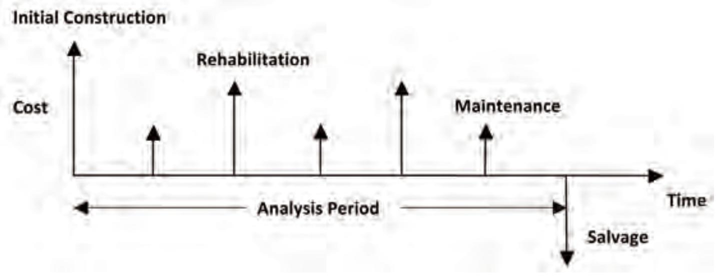


Figure 1. Costs Included in LCCA for a Paving Project

NPV is calculated using the following equation, which applies a discount rate to future costs in order to account for the time value of money.

$$NPV = Initial\ Const.Cost + \sum_{k=1}^{N} Future\ \ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] - Salvage\ Value \left[\frac{1}{(1+i)^{n_e}}\right]$$

where:

N = Number of future costs incurred over the Analysis Period
i = Discount rate, percent
n_k = Number of years from the initial construction to the k^{th} expenditure
n_e = Analysis Period, year

Setting the Analysis Period

In keeping with FHWA recommendations, the Analysis Period for LCCA should be a minimum of 35 years and include a "major rehabilitation" for both pavement types. The AASHTO Subcommittee on Maintenance defines "major rehabilitation" as "structural enhancements that both extend the service life of an existing pavement and/or improve its load carrying capability."

In many cases, concrete pavements reach the end of their service life and are rubblized or removed and replaced with either a new concrete or asphalt pavement. Such work is considered to be "reconstruction." A review of Alabama DOT interstate projects found that more than half of all concrete projects were reconstructed in less than 35 years. Similar results were found in other states. In contrast, complete reconstruction of asphalt pavements is extremely rare. Asphalt pavements are typically rehabilitated by milling and resurfacing, leaving most of the underlying asphalt structure intact. This type of rehabilitation can go on indefinitely.

Therefore, setting the Analysis Period in LCCA is an extremely important decision because it will impact how many rehabilitation activities are included in the NPV calculation, but also whether or not complete reconstruction of a pavement type must be considered.

Determining Salvage Value

Salvage Value is the expected worth of an investment at the end of the Analysis Period. For pavements, Salvage Value may include two components: serviceable life and residual value. Residual value—the net recyclable value—is generally small compared to the remaining serviceable life. Thus, the serviceable life of the structure at the end of the Analysis Period is a more significant consideration in LCCA.

For asphalt pavements, the Salvage Value term should include the remaining service life of the entire asphalt structure. "Most agencies that consider Salvage Value in LCCA only look at the remaining life of the last rehabilitation and neglect the value of the underlying asphalt structure that will continue to be used indefinitely. The approach we recommend is new in that it includes both parts in the salvage value," says Dr. Randy West, NCAT Director.

As shown in Figure 2, the asphalt structure at the end of the Analysis Period includes both the last resurfacing and the underlying asphalt layers still in service from the initial construction. The surface layers have a finite life. How much of that life extends beyond the Analysis Period is the remaining service life of the rehabilitation. But there is also a significant value for the underlying asphalt layers that will continue to serve as part of the flexible pavement structure indefinitely.

Figure 2. Changes in Asphalt Structure During Analysis Period

The following equation is used to accurately calculate the Salvage Value for an asphalt pavement. It includes both components—the remaining service life of the last resurfacing in addition to the value of the remaining lower asphalt layers.

$$Salvage\ Value = CLR \times \frac{Remaining\ Life\ of\ Last\ Resurf.}{Service\ Life\ of\ Last\ Resurf.} + CRI$$

where:

CLR = Cost of the last resurfacing
CRI = Cost of the lower asphalt layers remaining from the initial construction

When it is no longer feasible to maintain a concrete pavement at an adequate level of service, the cost of removal or rubblization should be considered in the LCCA. In the case of rubblization, the broken up concrete pavement does have a residual value as an aggregate base for the new pavement structure, but that value must be offset by the cost of rubblizing the concrete. For some projects, complete removal of old concrete pavements is necessary to avoid having to raise bridges and barrier walls, add new fill to slopes, and modify drainage structures. For these projects, the removal and disposal cost of the concrete must also be factored into the LCCA.

NCAT offers a variety of training opportunities to fit your needs. To register for a class or for more information, please visit our website: www.ncat.us or call Don Watson at 334.844.7306.

Need Training? NCAT's Got It!

Look no further for the most up-to-date asphalt training available. Whether you prefer traditional classroom training or online, self-paced training, NCAT has got you covered. Our course offerings are comprehensive—ranging from a general overview of asphalt materials and construction to in-depth instruction on current topics such as warm-mix asphalt (WMA) and designing high-RAP content mixes. Options are available for both individuals and groups.

Upcoming Classroom Training Dates at NCAT

Advanced Mix Design: January 27-29, 2014
Asphalt Technology: February 24-28, 2014
Superpave Mix Design: March 24-28, 2014

Our traditional classroom sessions include the ever-popular Asphalt Technology Course, Superpave Mix Design and the new Advanced Mix Design course. Advanced Mix Design is a three-day course covering the use of WMA, RAS and high percentages of RAP. All facets of these technologies are discussed, from mix design procedures and performance testing, to production and placement, QC/QA, observed performance, economics and guide specifications. Each course includes an optional tour of the NCAT Pavement Test Track.

Here's what recent participants of the Asphalt Technology Course have to say:

"…[I] cannot say enough good things about the instruction and the materials presented at the course. There was a healthy mix of public and private sector participants which provided different perspectives to each subject matter." –Sean Lehocky, project engineer, City of Commerce City, Colorado

"The instructors from the institute are very professional and knowledgeable…Of course, the highlight of the week was the visit to the asphalt test track. You hear so much about it but it's tough to imagine until you actually see it; the scale, the care, management and evaluation of the sections that comprise the track." –Patti Sinclair, Q.C. Technician

"The course provided me with a greater understanding as to what goes on in the 'lab' and why testing is so critical…Being more on the side of preservation treatments, I was surprised to see that NCAT has placed numerous test segments of surface treatments (20 or so) and will be documenting their performance. I look forward to seeing the results and the chance to utilize such treatments in the Town of Castle Rock." –Kevin Smith, Town of Castle Rock, Colorado

"…The presenters did an excellent job of explaining everything on a level that anyone could understand." –Jeffrey P. Cuypers, senior laboratory technician, CESARE, INC.

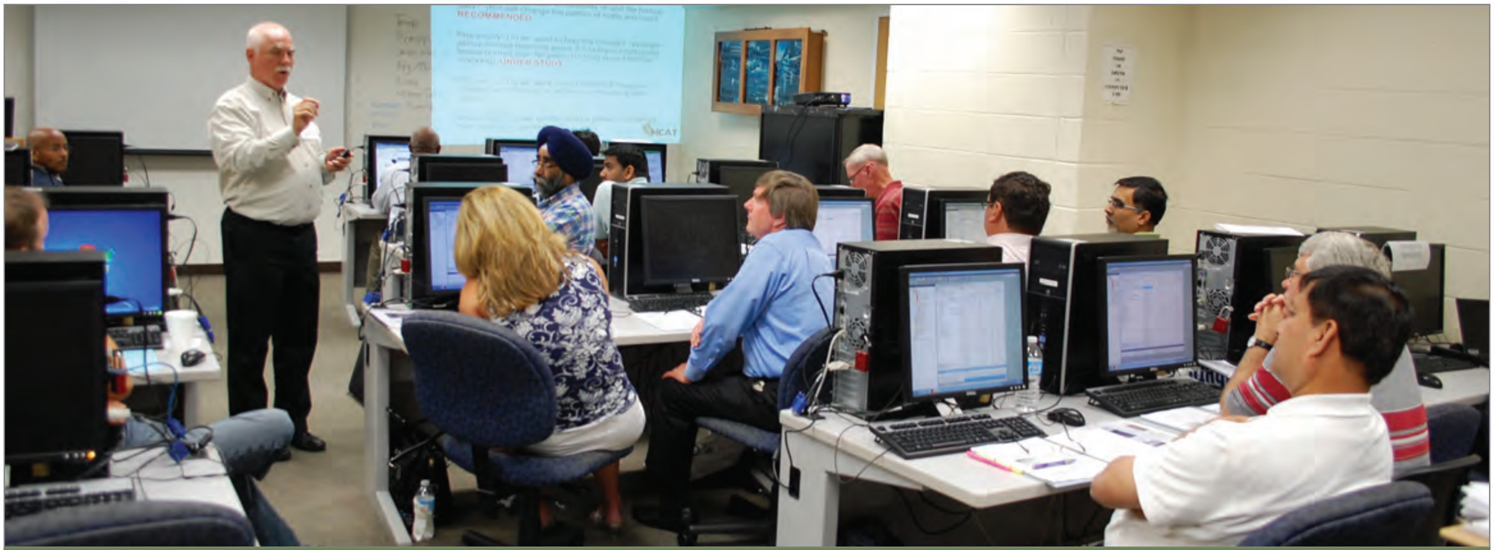
(All reprinted from the May 9, 2013 issue of the Colorado Asphalt Pavement Association's e-newsletter, *In Front of the Paver*.)

NCAT can also provide customized training to meet your individual training needs. Workshops can be conducted at our facilities or yours, at a time convenient for you. Onsite workshops allow agencies and contractors to make the most efficient use of their training budgets while complying with imposed travel restrictions. Workshops can also be tailored to fit the technical needs of your personnel.

If you're looking for online options, a variety can be found at **www.ncat.us**. A free four-part webinar series on implementing WMA is available, as well as free training videos on recognizing pavement distresses, recycling asphalt mixtures, and a WMA overview. You can also earn continuing education credits through online professional development courses offered by Auburn University's Office of Continuing Education. These classes, taught by NCAT staff and professors in Auburn's Department of Civil Engineering, cover a wide range of pavement engineering topics (see sidebar) and vary in length from 1 to 6 hours. Pricing is available for both individuals and organizations, and credits are approved and/or accepted for engineering professional development requirements in most states. A link to these continuing education classes can be found on our website, or go directly to **www.eng.auburn.edu/online/distance-education/epd-program/course-listing/civil-structural.html**.

Online Professional Development Courses Offered Through Auburn University

Aggregate Properties and Testing—1 hour
Asphalt Binder Tests and Specifications—2 hours
Asphalt Mix Design—3 hours
Asphalt Pavement Preservation and Rehabilitation—5 hours
Basic Pavement Distress Evaluation Principles—3 hours
Hot Mix Asphalt Compaction—1 hour
Hot Mix Asphalt Delivery and Placement—1 hour
Hot Mix Asphalt Paving Construction Specifications and QC/QA—3 hours
In-Place Asphalt Recycling, FDR and Soil Stabilization—3 hours
In-Place Asphalt Recycing, HIR and CIR—3 hours
MicroPaver Pavement Evaluation—3 hours
Pavement Management Systems—1 hour
Pavement Preservation Techniques—3 hours
Soils for Pavements—6 hours



A Mechanistic-Empirical Pavement Design Workshop sponsored by FHWA in cooperation with NCAT was held at Auburn University, August 13-16, 2013.

Asphalt Mix Design Class held at the Materials Office in Bayamon, Puerto Rico, September 24-27, 2013

A Russian group representing both state and federal agencies, as well as private industry, visited NCAT for Superpave Mix Design training, May 28-31, 2013

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HiMA Mat on Oklahoma I-40 Project (photo coutesy of Kraton Polymers LLC)