MWV Specialty Chemicals

A Scientific Study and Analysis Report
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April 2009

MWV Evotherm™ Pavement Durability: Results of Laboratory and Field Testing

EVOTHERM
WARM MIX ASPHALT TECHNOLOGY

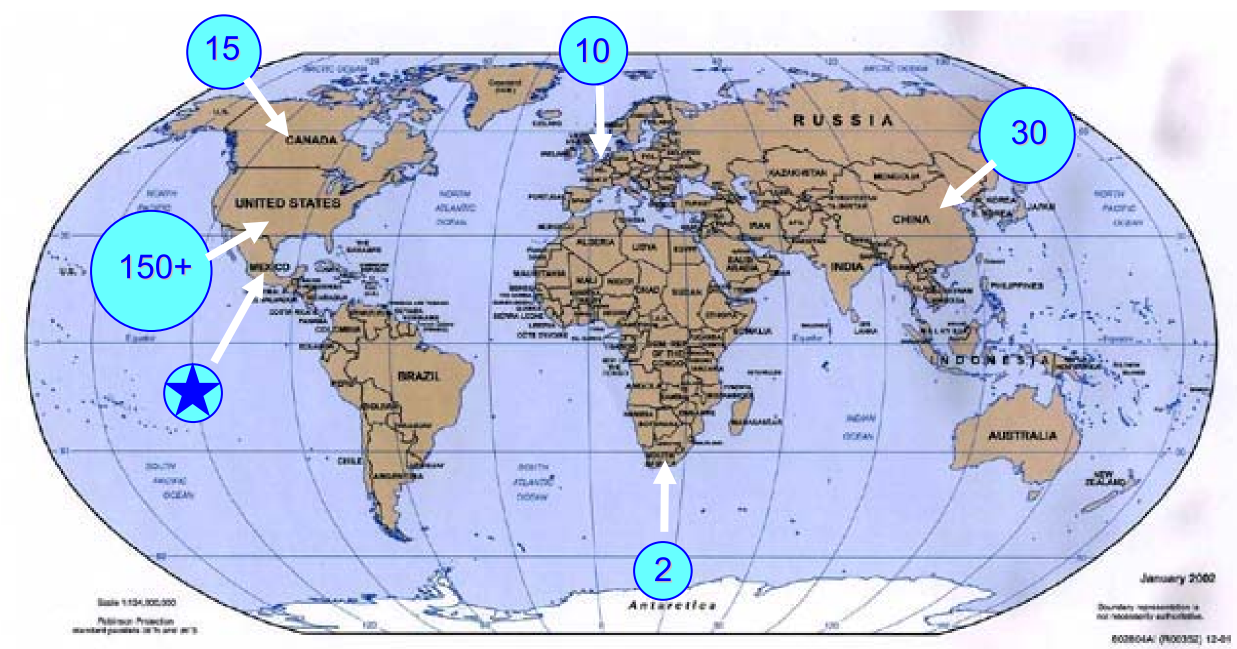
Note to reader: Blue, underlined text provides hyperlinks to files containing additional relevant information.

Background

The development of Evotherm™ warm mix asphalt (WMA) technology was undertaken initially as a means of achieving numerous environmental and human health benefits during production of asphalt mix and construction of asphalt pavements. It soon became clear, however, that Evotherm warm mix asphalt technology could yield a number of other benefits, such as extended haul distances, expanded paving season, quicker return to traffic, and high RAP incorporation, to name a few.

Moreover, after four years of extensive laboratory and field study, it has become apparent that Evotherm technology provides a means of producing more durable asphalt pavements while simultaneously achieving the aforementioned environmental, human health, and constructability benefits. Over 200 projects have been undertaken worldwide consuming over 500,000 tons of mix. Evotherm mixes in these projects have used all classes of aggregate, RAP, and binder materials. Production and construction operations in these projects have involved all range of practices common in today's asphalt paving industry. Project locations have varied in climatic extremes. In all of these projects, under all of these varied conditions, the Evotherm pavements have proven to perform as well as or better than the corresponding hot mix asphalt pavements.

Evotherm Projects as of December 2008



Mix plants owned & operated by Mexico City, D.F., now produce Evotherm mix 100% of the time.

EVOTHERM

This report highlights the salient results of numerous field studies and laboratory tests that indicate Evotherm pavements are more durable than comparably formulated and constructed hot mix asphalt (HMA). A brief outline of each study is given below. The reader is urged to use the hyperlinks indicated by blue, underlined text to access more information about a given topic, photos of job sites, and literature relevant to the subject of Evotherm pavement durability.

Outline and Summary of Eight Topics in this Report ***Pages***

Field Projects: Brief Summary

Two key accelerated load projects are highlighted in which Evotherm warm mix asphalt pavements, constructed at temperatures ranging from 50 to 100°F (30 to 50°C) below the HMA control, performed as well as the HMA control. Also, numerous field projects are highlighted in which Evotherm technology was used to construct pavements subjected to very high loads.

Over 10 million ESAL's were placed on the Evotherm sections without rutting, cracking, or moisture damage. Evotherm pavement was constructed at 55 to 102°F (31 to 57°C) lower temperatures than HMA control sections.

Evotherm mix was produced at 250°F (121°C) and HMA control produced at 315°F (157°C). No rutting difference was observed between Evotherm pavement and the HMA control, with both subjected to identical, severe loading conditions.

Evotherm pavements have been constructed on heavily trafficked highways in the U.S. using a variety of mix types, including dense-graded mixes with high RAP content, SMA mixes, and SMA ground tire rubber mixes with RAP. These pavements, constructed in wide ranging climates, all have performed well.

Laboratory Studies: Brief Summary

A number of laboratory studies of thermal cracking, overlay cracking, and fatigue are highlighted, which demonstrate the improved fracture resistance of various types of Evotherm mix formulations compared to HMA control mixes.

The DC(T) thermal cracking test results showed that plant-produced, lab-molded PG 64-22 dense-graded Evotherm mixes exhibited higher resistance to cracking than identical HMA at temperatures ranging from -10 to -30°C.

The overlay cracking tests using lab-made PG 64-22 dense-graded granite and limestone mixes also showed an order of magnitude difference in performance.

<u>Binder Analyses: Brief Summary</u>

Numerous binder analyses have been conducted on recovered Evotherm binders. These analyses repeatedly demonstrate that use of Evotherm technology results in significantly less binder aging than that resulting from conventional HMA production processes.

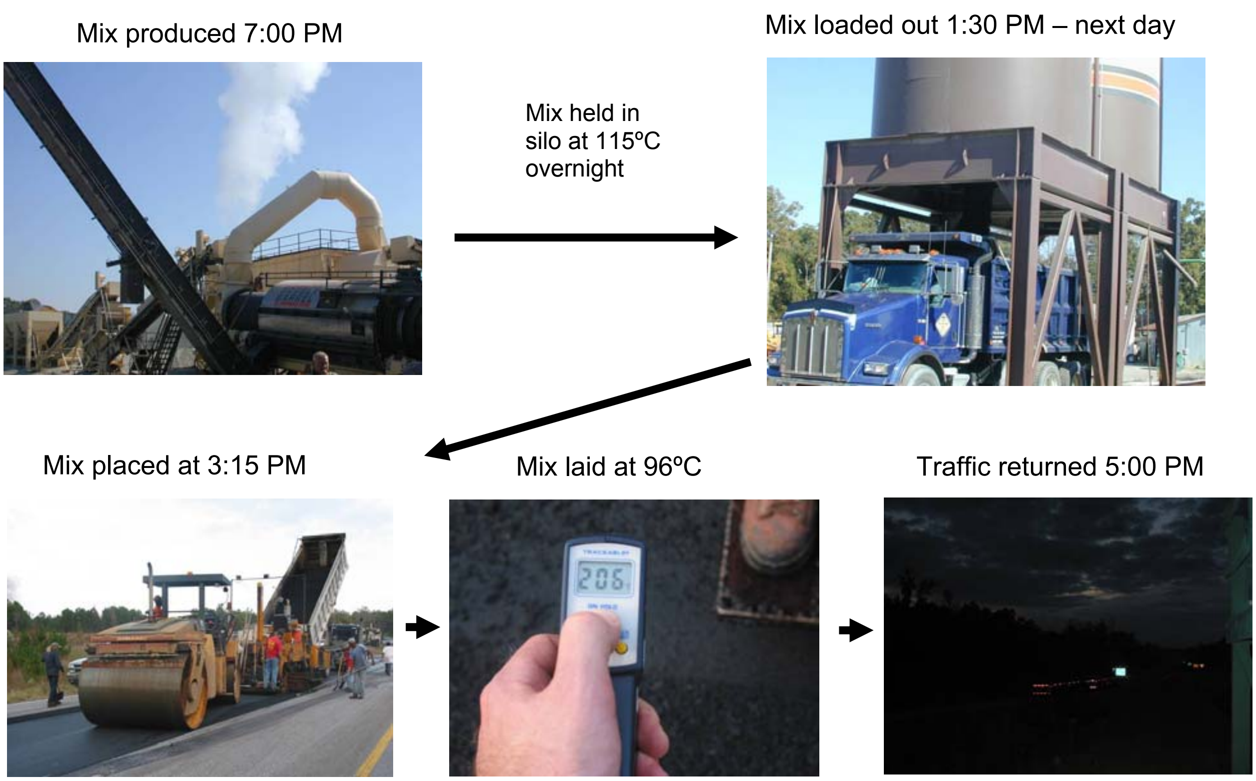
Field Projects

I. *NCAT Test Track Project Reveals No Distress in Evotherm Pavement after More than 10 MM ESAL's*

The results of this project have been widely discussed (1). Figure I-1 shows essential elements of the construction process. Figure I-2 shows a cross-section of the in-place Evotherm sections built at the NCAT Test Track in Oct. 2005. The PG 76-22 surface mix on ET is an overlay.

FIGURE I-1

Construction Process Overview



Photographs courtesy of B. Prowell, Ph.D., P.E., Advanced Material Services, LLC., Auburn, AL.

FIGURE I-2

Schematic Cross-Section of Evotherm Test Sections at NCAT (not to scale)

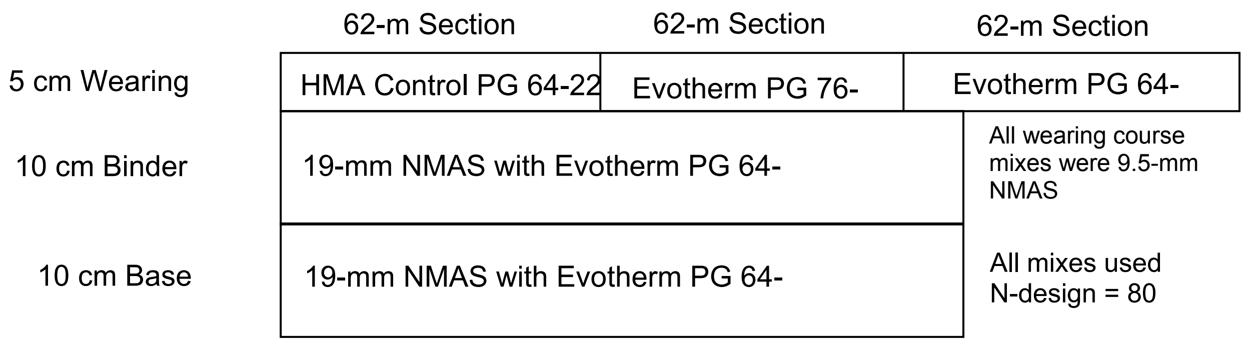
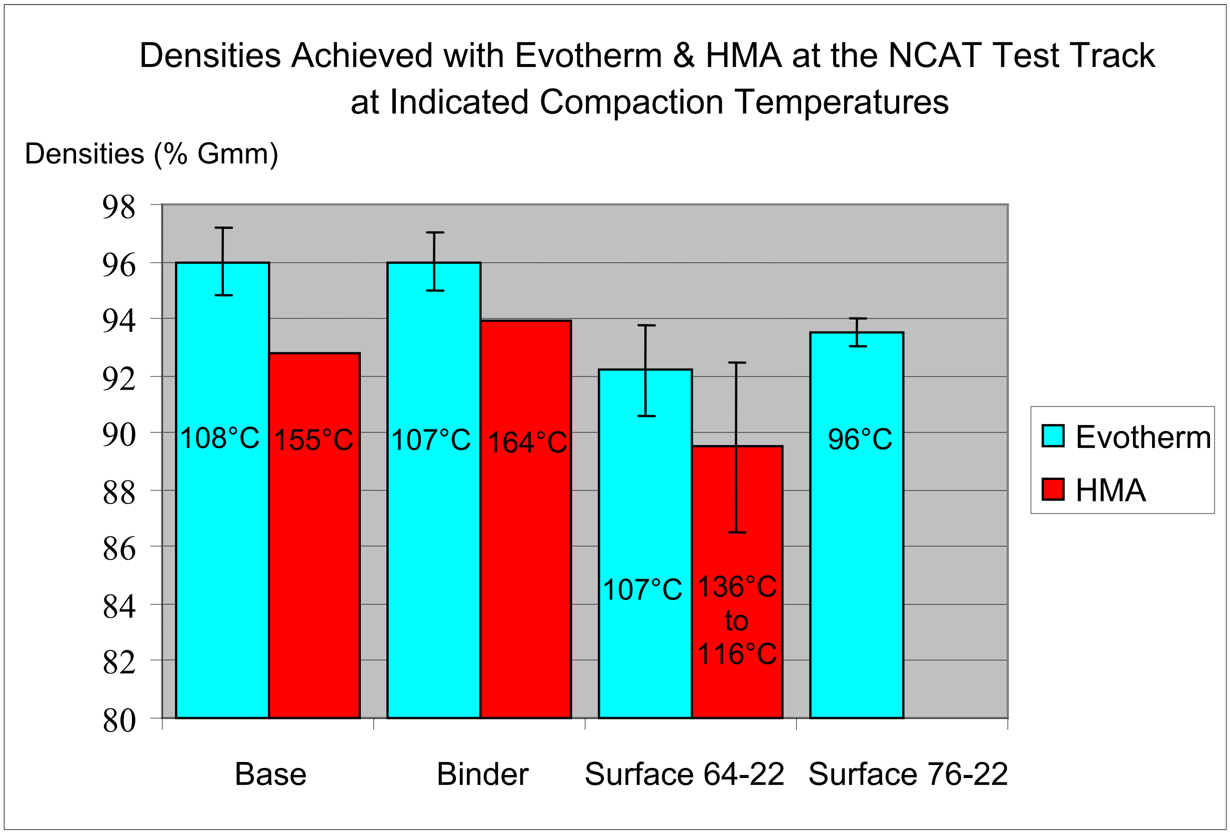


Figure I-3 shows compaction temperatures for the various Evotherm pavement layers constructed at the Test Track along with typical temperatures for comparable HMA layers built at the track. Evotherm construction temperatures (laydown and compaction) were roughly 55-100°F (30-60°C) lower than the HMA temperatures. Despite these large differences in temperature, the densities of the Evotherm pavements were better than those of the HMA control sections.

FIGURE I-3

Construction Temperatures



Early Deformation Experiment.

At the Test Track after construction of new sections, the fleet of five, multiple-axle trucks are returned to the track in a staged manner. That is one truck is allowed to run the track for a prescribed period of time (each truck runs about 680 miles per day) to achieve post consolidation of the freshly-built sections. Slowly, in a similar manner, the remaining four trucks are returned to the track.

The Evotherm test sections were not treated in this manner. Rather, as soon as the compaction was completed and the construction equipment and personnel were removed from the work zone, all five, multiple-axle trucks were returned to the track. Despite this very heavy load of immediate traffic, there was no deformation observed in the Evotherm pavements.

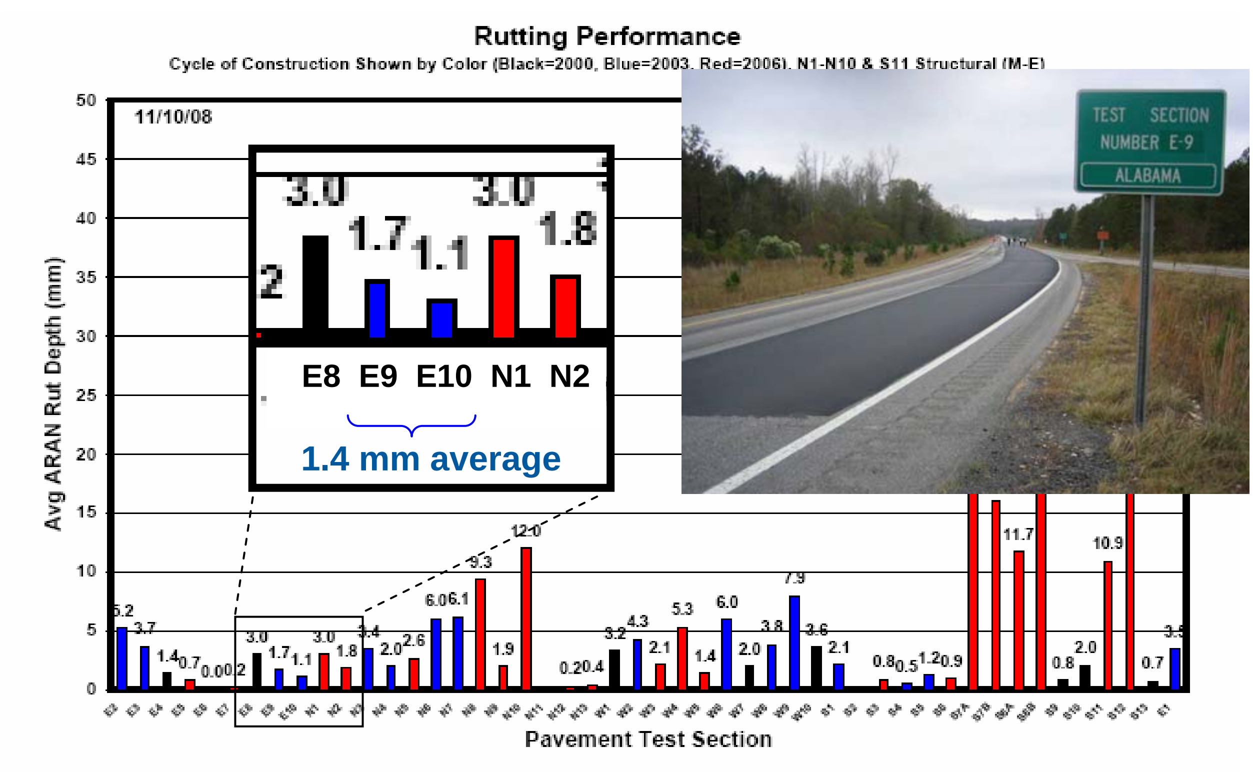
Evotherm PG 76-22 and PG 64-22 Overlays after more than 10,000,000 ESAL's

By 2006, the Evotherm sections had experienced over 600,000 ESAL's without deformation, as noted above. During the scheduled 2006 NCAT Test Track re-build, the Sections N1 and N2 were removed. However, a portion of Evotherm N1 PG 76-22 surface mix remained as an overlay adjacent to the Evotherm E9 PG 64-22 overlay. The PG 76-22 Section was renamed E10.

By November of 2008, the E9 and E10 Evotherm overlays had experienced over 10 million ESAL's. Figure I-4 is an excerpt from the NCAT Test Track website, www.pavetrack.com, taken November 10, 2008. The data relative to Sections E9 and E10 are expanded for better resolution. One can see that after more than 10 million ESAL's, the rut depths of E9 and E10 were 1.7 and 1.1 mm, respectively, for an average of 1.4 mm.

FIGURE I-4

No Deformation (Rutting) in Evotherm Sections after Over 10 Million ESAL's



Field Projects

II. *Caltrans Heavy Vehicle Simulator Tests Showed Evotherm Performed the Same as HMA Control*

In 2007, Caltrans sponsored the construction of warm mix pavement test sections at the Graniterock, Inc., A.R. Wilson quarry, near Aromas, California. The work was overseen by the University of California Pavement Research Center, under the direction of Dr. David Jones, who has reported on results to date (2a). The Evotherm test section was produced and compacted at roughly 121°C (250°F) or 35°C below the HMA control section, which was based on a conventional Granite Rock mix formulation. All mixes were Type A 19 mm dense-graded asphalt mixes containing approximately 5.3% PG 64-16 bitumen (by weight of mix). The average air voids of the HMA control and Evotherm section were 5.6 and 7.0%, respectively. The warm mix and control sections were subjected to testing with a Heavy Vehicle Simulator (HVS) designed and constructed by the Council for Scientific and Industrial Research (CSIR) in South Africa (2b). The accelerated load capabilities of HVS units can deliver 20 years of service in two to three months (at typically, 40,000 ESAL's per day). Additionally, HVS units are designed to simulate environmental influences by enabling load tests to be conducted at elevated temperatures or on moisture saturated pavements.

Figure II-1 shows the Heavy Vehicle Simulator used to assess the performance of the Evotherm pavement compared to that of the HMA control. In this study, deformation was measured on pavements heated to 50°C at a depth of 50 mm.

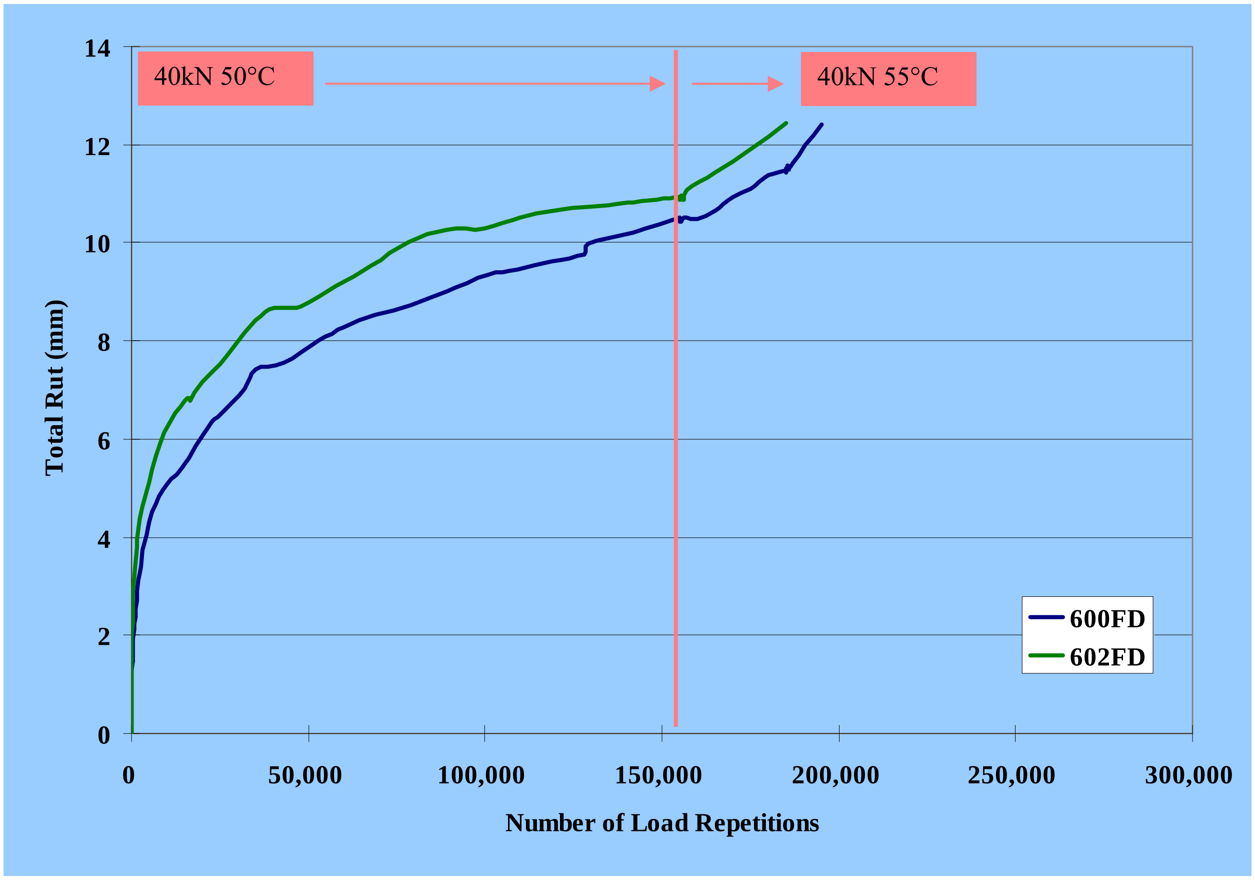
FIGURE II-1

Heavy Vehicle Simulator

Figure II-2 shows the results of comparative analysis of the performance of the HMA control section and the Evotherm warm mix asphalt pavement section. There was essentially no difference in the rutting behavior of the Evotherm and HMA control mixes under these conditions.

Figure II-2

Equal Rutting Performance for Evotherm WMA and HMA Control Sections under HVS Testing (Evotherm is Green Curve, 602FD)



Graph courtesy of Dr. D. Jones, Pavement Research Center, UC Davis.

It is important to note that the temperature at 50 mm depth in both the control HMA section and the Evotherm warm mix asphalt pavement were raised to 55°C at roughly 160,000 repetitions. Without this increase in temperature from 50 to 55°C, neither pavement would have reached the failure rut depth of 12.5 mm. At the elevated temperatures, the Evotherm pavement reached the target failure criterion depth at 185,000 repetitions; the HMA pavement reached the failure rut depth at 195,000 repetitions.

Dr. Buzz Powell, Director of the NCAT Pavement Test Track, has calculated that each pass of the HVS dual wheel (at the load of 40 kN and velocity of 10 kpm used in this experiment) delivers the equivalent of 1.1 ESAL's (3). Thus, at a pavement temperature of 50-55°C the Evotherm and HMA pavements experienced rut failure depths at 4.1 and 4.3 million ESAL's respectively.

Field Projects

III. *Heavy Traffic, High Load Pavements Constructed with Evotherm Have Shown No Distresses*

In addition to the NCAT Pavement Test Track, Evotherm technology has been used on a number of other projects with high ESAL loads. In 2005, for example, many early Evotherm test projects included the exit roads to quarries, asphalt mix plants, and, in one case, a Redi-mix Portland cement concrete plant. Since that time, Evotherm has been applied on multilane highways in industrial zones with heavy truck traffic (such as Hall Road, St. Louis, MO; Loop 368, Austin, TX; and BU 287, Ft. Worth, Texas) as well as interstate highways. Table III-1 lists some of the heavy-load, high-traffic Evotherm projects. To date, none of these pavements has shown any signs of pavement distress.

TABLE III-1.

Selected Evotherm Warm Mix Asphalt Projects on U.S. Interstate Highways

Project	Location	Aggregate	Binder	Date
Hall Rd.	St. Louis, MO	SP 12.5 mm Trap Rock 10% RAP	PG 70-22	May '06
Loop 368	Austin, TX	Type C (19 mm)	PG 76-22	Sept. '06
I-70	Colorado	SP 9.5 mm	PG 58-28	Aug. '07
BU 287	Ft. Worth, TX	19 mm base & binder 9.5 mm surface	PG 64-22 base PG 76-22 surface	May '08
SR-71	Austin, TX	Type C	PG 64-22 base PG 76-22 surface	Aug. '08
I-35	Austin, TX	SMA	PG 76-22	Aug. '08
Route 44	St. Louis, MO	12.5 mm + 20, 28, & 35% RAP	PG 70-22	Sept. '08
I-78	Clinton, NJ	SP 12.5 mm + 25% RAP	PG 76-22	Nov. '08
I-90	Chicago, IL	SMA	PG 76-22 crumb rubber	Nov. '08

Many of the above projects in Table III-1 as well as other Evotherm projects have been described in the U.S. asphalt paving literature not only because of the success of the warm mix application, but also because of unique benefits that the technology may have provided in terms of constructability, such as extended haul distances, expanded paving season, quicker return to traffic, and high RAP incorporation (4a) (4b) (4c).

Also, a thorough engineering report on the BU 287 project is available (5). In 2008, this 57,000-ton project won the prestigious National Asphalt Paving Association (NAPA) Quality Construction Award.

Laboratory Tests

IV. *DC(T) Testing for Low-Temperature Thermal Cracking Resistance Show that Evotherm Mixes Exhibited Better Resistance to Cold Fraction than HMA Controls*

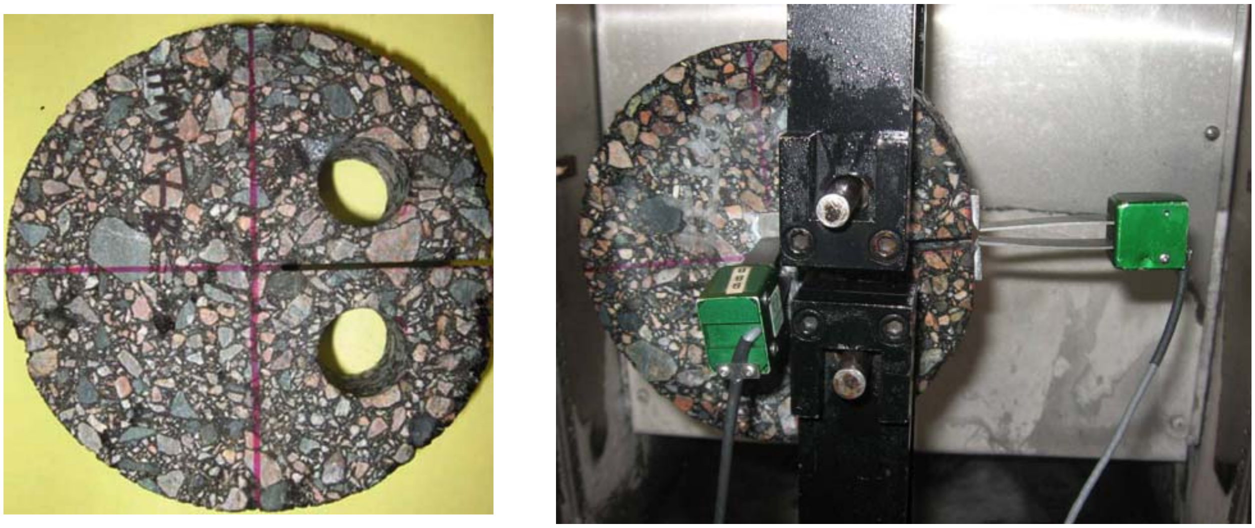
Evotherm technology enables contractors to reduce production temperatures 35 to 55°C compared to his typical hot mix asphalt temperatures. This reduction in temperature reduces oxidation of the binder. Reduced binder oxidation leads to a variety of benefits, particularly as regards crack resistance.

Dr. William Buttlar, University of Illinois Urbana-Champagne, conducted Disk-Shaped Compact Tension Tests on plant-made, lab-molded Evotherm mixes. The test is known in the industry as the DC(T) test. Dr. Buttlar has published extensively on the use of this test as a means of precisely measuring thermal cracking properties of asphalt mixtures (6), (7).

The Evotherm mix used in this study was a 12.5 mm NMAS granite containing roughly 5.0% PG 64-22 binder by weight of mix. It had been produced in a counter-flow Gencor plant at 115°C. The HMA mix was comprised of the same materials but was produced at roughly 150°C. Figure IV-1 shows how test specimens were altered and configured within the test device. Procedures for preparing and testing specimens follow ASTM 7313-07.

FIGURE IV-1

Configuration of Test Specimens and the Load Cell and Environmental Chamber



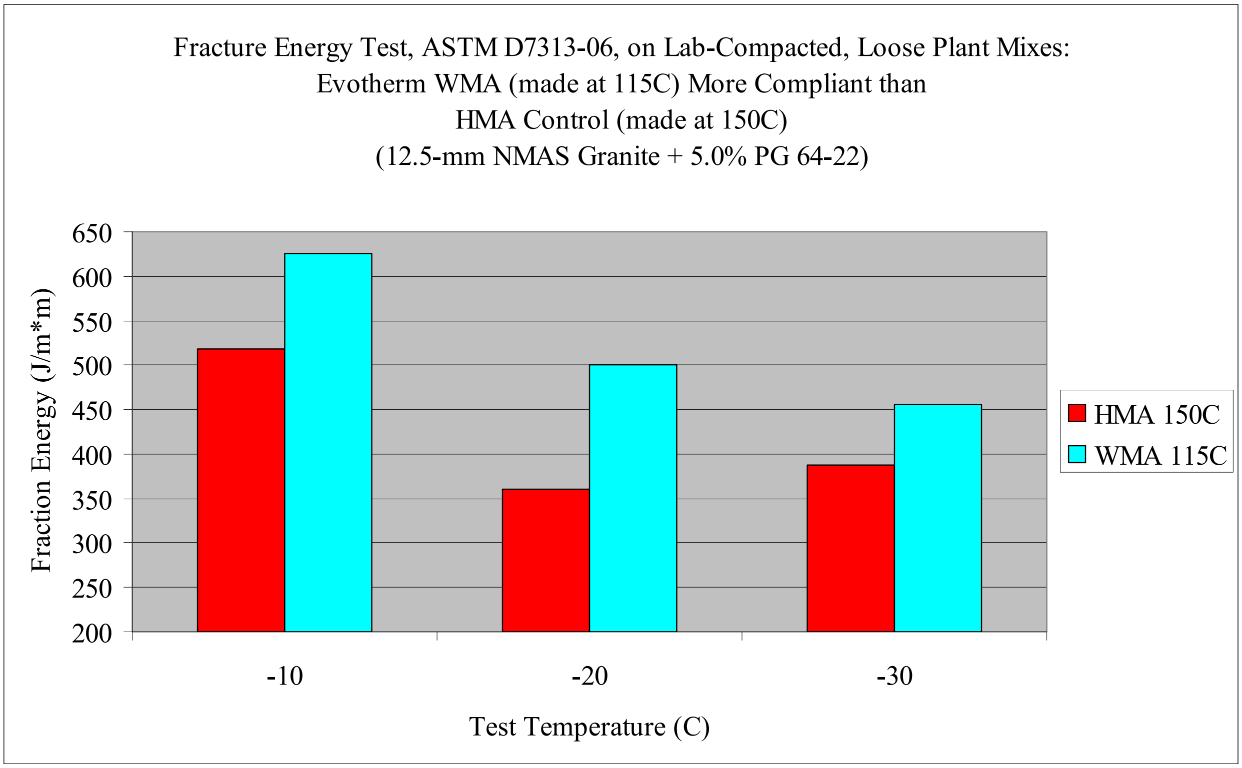
Photographs from Dr. W. G. Buttlar, University of Illinois, Urbana-Champagne, reference 6-7.

The test specimens were subjected to repeated load at three fixed temperatures: -10, -20, and -30°C. The test temperatures were chosen to bracket the low-temperature grade of the binder used in the mixture formulation, i.e., -22.

The test results were analyzed to determine the cumulative energy required to create a crack the specimen at the indicated test temperature. The higher the energy, the more resistant the pavement is to cracking. Figure IV-2 shows the results of these analyses in graphical form. The Evotherm samples were more resistant than the identically formulated HMA specimens.

FIGURE IV-2

Fracture Energy via DC(T) Test of Evotherm versus HMA
(Superpave 12.5 mm NMAS, PG 64-22)



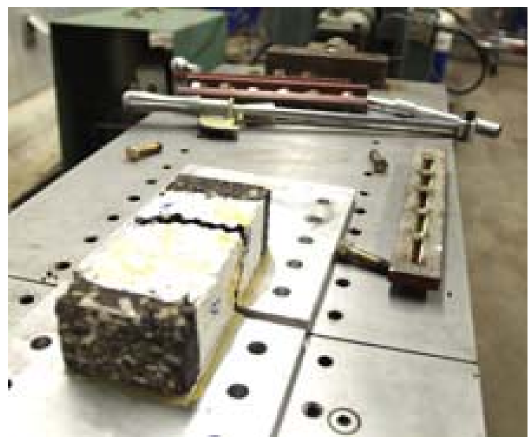
Laboratory Tests

V. *Overlay Tests Results Show that Evotherm Mixes Resist Stress Fracture Significantly Better than HMA Controls*

It was observed in field cores from the Loop 368 project in Austin, Texas, that absorption of asphalt into the aggregate in the HMA control mix (produced at 166°C) was significantly higher than in the Evotherm warm mix (produced at 115°C). Less absorption not only means a more effective use of the binder, but numerous implications follow with regard to performance. Chief among these is resistance to cracking.

Overlay tests were conducted at the Texas Transportation Institute to compare the overlay crack resistance of Evotherm warm mix to HMA. The overlay test is routinely applied by the Texas Department of Transportation to evaluate compacted specimen crack resistance. The fundamentals of the overlay test have been discussed extensively in the literature (8a) (8b). Essentially a repeated triangular strain is applied to the specimen until it cracks. Figure V-1 shows the Overlay Tester assembly with a specimen epoxied to the test plate as well as a view of the specimen after cracking. A key measurement of the test is the cycles to failure.

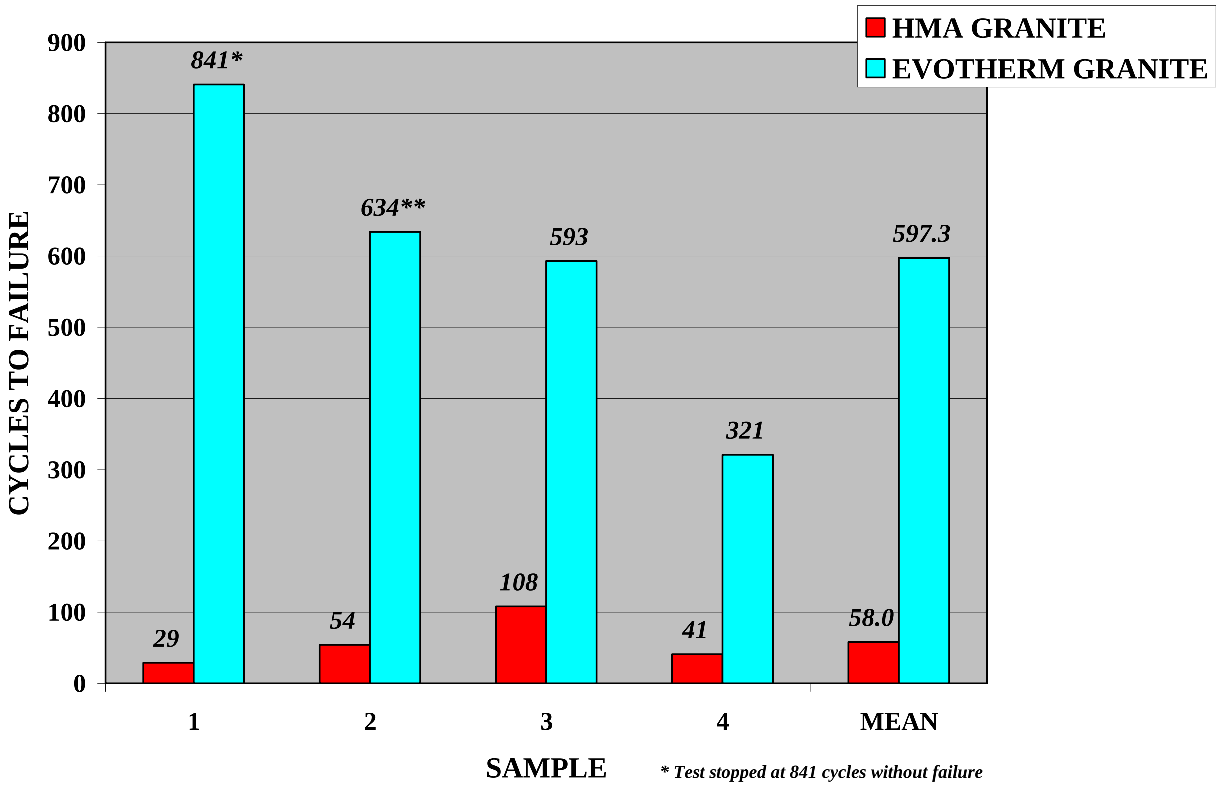
FIGURE V-1
Overlay Tester



Photographs from T. Scullion, et.al., Texas Transportation Institute, reference 8a) and 8b).
Warm mixes and HMA control mixes based on limestone and granite were examined. The binder was PG 64-22 in all cases. Warm mix and hot mix production temperatures were 115°C and 152°C, respectively. Figures V-1a and V-1b show the results of these tests.

FIGURE V-1a

PG 64-22 Granite Mixes

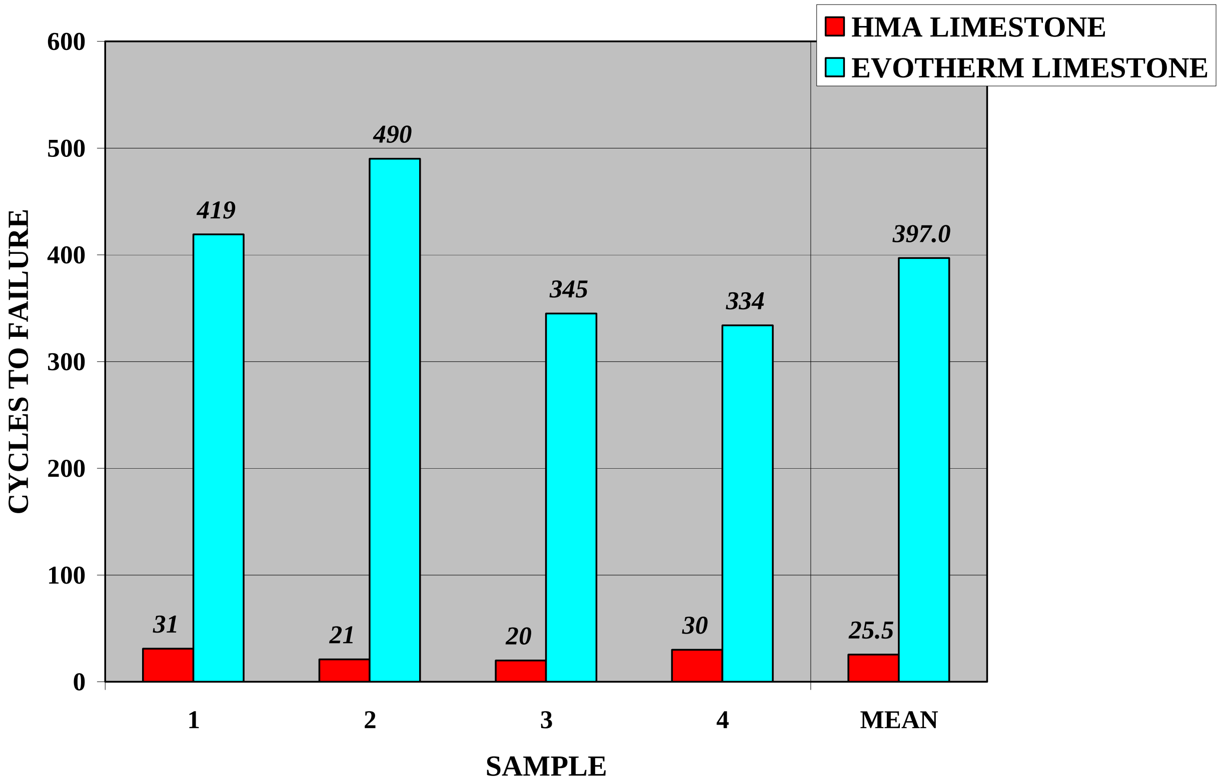


** Test stopped at 841 cycles without failure*

*** Test stopped at 634 cycles without failure*

FIGURE V-1b

PG 64-22 Limestone Mixes



The overlay test results showed that the Evotherm mixes, made at 115°C, exhibited an order of magnitude greater resistance to cracking than the identically-formulated HMA control mixes, made at 152°C.

Laboratory Tests

VI. *Fatigue Studies Demonstrate the Superior Performance of Evotherm Mixes versus HMA Controls*

The Evotherm additive package enables mixing and coating at temperatures 35-55°C below that of conventional hot mix asphalt. Reduction in mix temperatures means less binder oxidation. Reduced binder oxidation leads to a more crack-resistant mix, as seen in thermal cracking and overlay cracking studies. The effect of reduced binder oxidation has been observed to improve fatigue behavior of compacted Evotherm mixes as well. The observation of improved fatigue behavior in warm mix asphalt was previously reported by Shell Corporation that developed the WAM foam warm mix technology (9). Additionally, the improvement in fatigue behavior is consistent with the well-established impact of oxidation on the fatigue performance of conventional HMA, as reported by Epps-Martin of Texas A&M University (10). Notably, higher binder oxidation leads to embrittlement of the binder and a lower resistance to crack development and propagation as measured in cycles to failure, cumulative dissipated pseudo strain energy, or other fatigue responses.

Three four-point beam fatigue studies have been conducted. The type of mix varied in each study: SMA, dense-graded AC13 (Chinese specification), and SP 12.5-mm dense-graded (denoted here SP125). The AC13 dense-graded mix is a typical formulation in mainland China and was made with a 70-pen binder and a 13-mm top-size dense-graded aggregate. The SP125 mix comprised 4.6% PG 64-22 binder by weight of 12.5 mm NMAS dense-graded granite aggregate. All tests were conducted with HMA control. All tests used beams molded in the lab from loose plant mix. Figures VI-1a through VI-1c show the results of these tests. The natural log of cycles to failure is plotted with respect to micro-strains. In all cases, the warm mix beams showed higher cycles to failure (Nf) at a given micro-strain (με) level than the HMA controls. The percent difference in the Evotherm over the HMA beam Nf values are given in each Figure for each micro-strain level. At low micro-strain levels, the Evotherm mixes clearly gave better fatigue performance.

The improved performance at low micro-strain levels has significant practical importance. Prowell (11) reported that the endurance limit for a PG 64-22 dense-graded mix was approximately 150 micro-strains. In other words, below this level of strain, one would not expect fatigue failure, from bottom up cracking, over an essentially infinite number of loading cycles. Therefore, the data in Figures VI-1a, VI-1b, and VI-1c indicate that the Evotherm pavements would provide longer service life than the HMA control.

FIGURE VI-1a

Fatigue Study Results on SMA Mixes

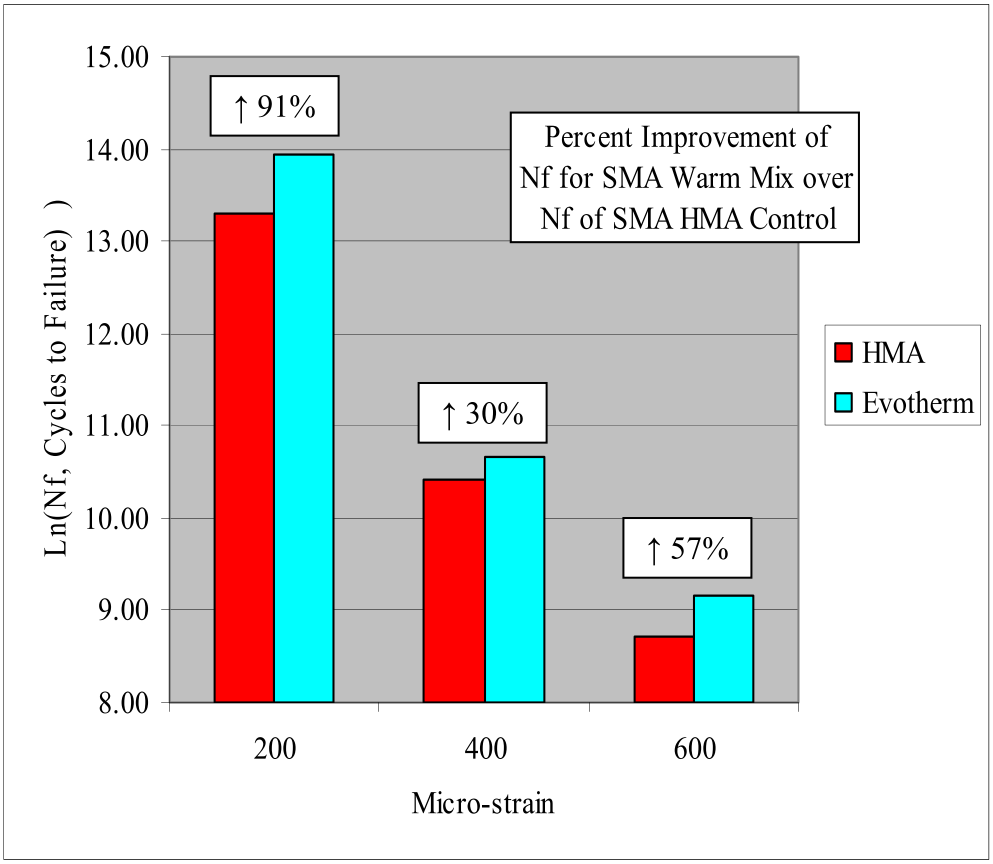


FIGURE VI-1b

Fatigue Study Results on AC13 Chinese Dense-Graded Mixes

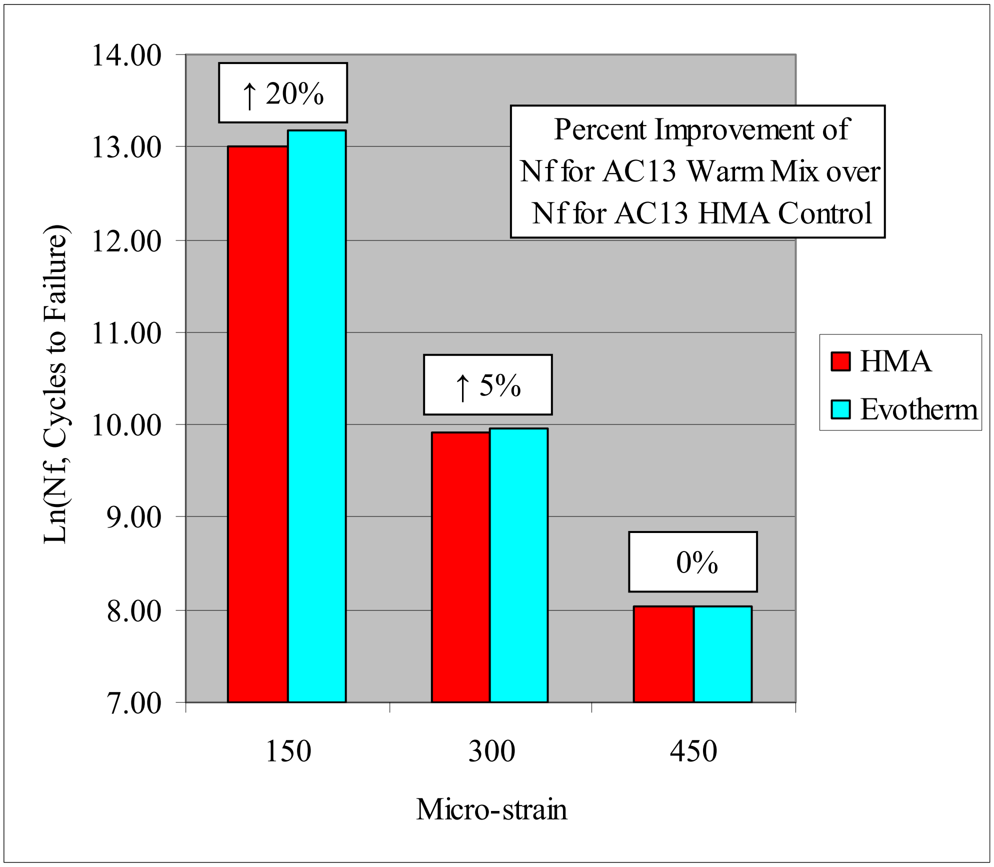
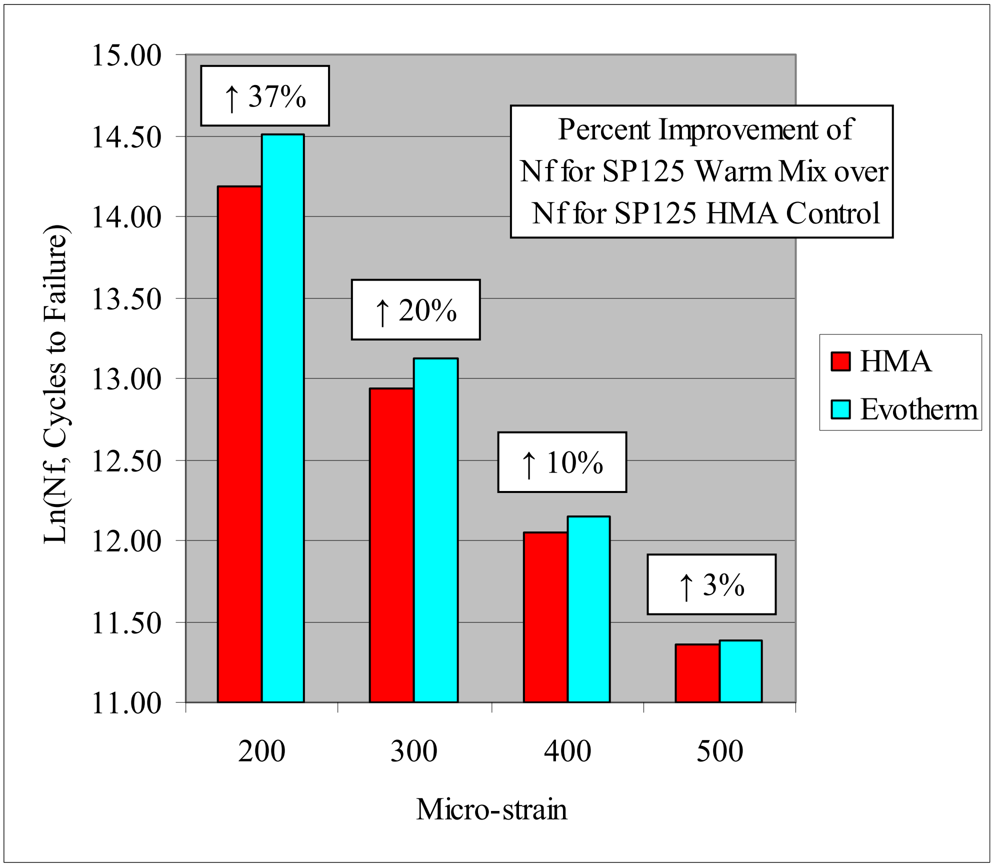


FIGURE VI-1c

Fatigue Study Results on Superpave 12.5 mm NMAS PG 64-22



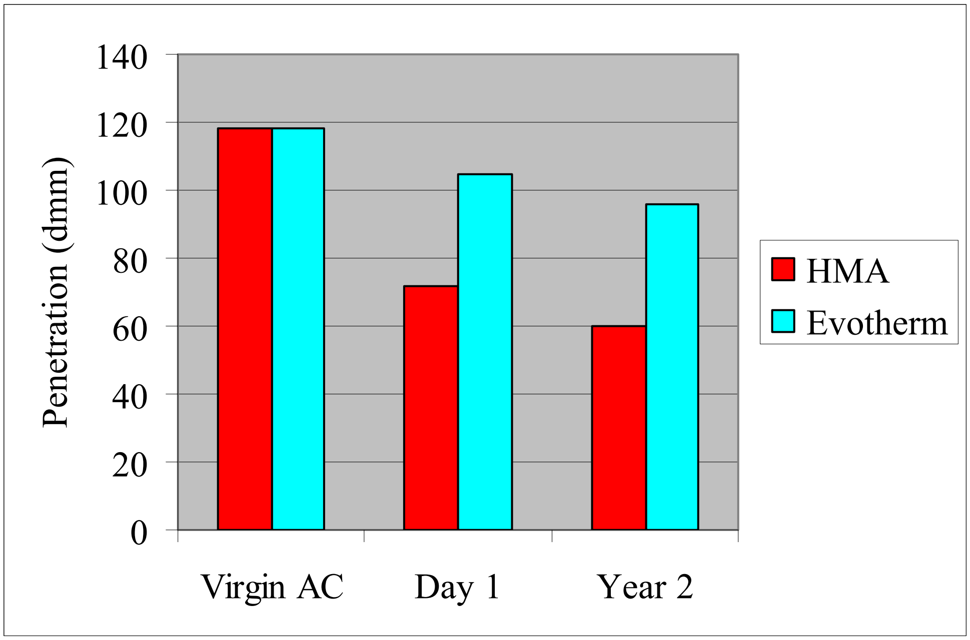
Recovered Binder Analyses

VII. *Penetration Values of Recovered Binders Reveal that Evotherm Mixes Are Less Aged than HMA Control Mixes*

In numerous projects, loose plant mix has been collected and subjected to conventional Abson recovery procedures (ASTM D 1856). In one project, the penetration of the starting binder was compared to the penetration values (at 25°C, 5-second test) of the recovered binder from mix taken on the day of production and from field cores taken from the pavements two years after placement. Figure VII-1 shows the results of these analyses.

FIGURE VII-1

Penetration Values of Recovered Binder Show Aging Effects

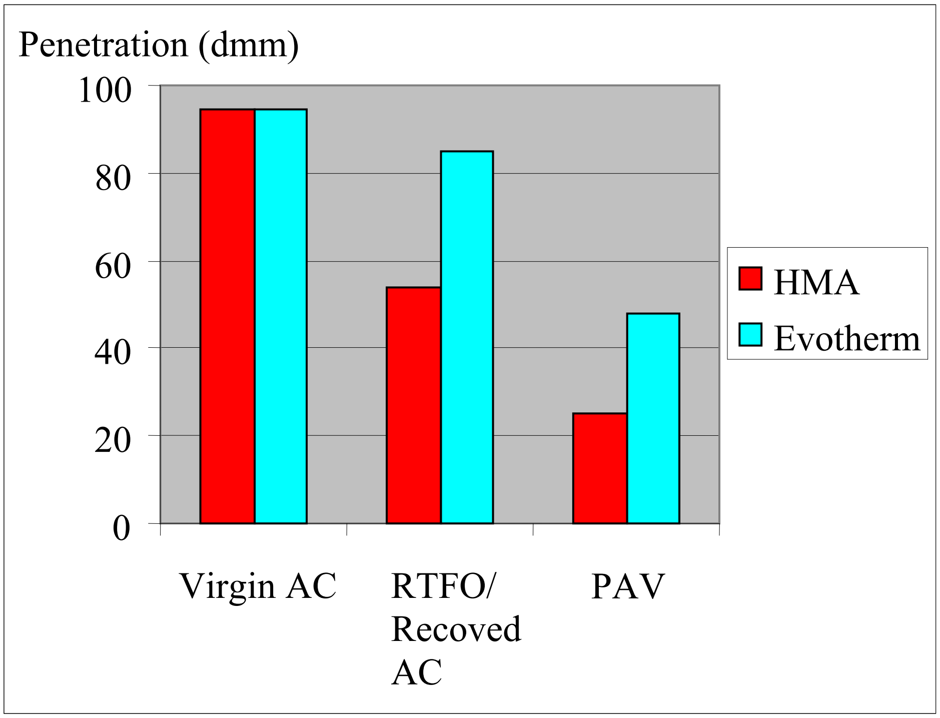


On day-1, the HMA production conditions led to a decrease of 39% in the binder penetration value, whereas the binder penetration value for the Evotherm mix dropped only 11%. Similarly, after two years of service, the binder extracted from the HMA core had dropped 49% from the penetration value of the virgin binder. The binder extracted from the Evotherm core had dropped 19% from the penetration value of the virgin binder.

Figure VII-2 shows the results of a similar analysis. Virgin binder was subjected to conventional RTFO to simulate mix production and then the penetration was measured. The penetration value of the RTFO HMA sample was compared to that of recovered Evotherm binder. Again the aging of the Evotherm binder was significantly reduced compared to the virgin binder submitted to RTFO. Moreover, when the RTFO-treated binder and Evotherm recovered binders both were submitted to PAV aging, the penetration of Evotherm binder again revealed that it was less oxidized than the control binder.

FIGURE VII-2

Penetration Value of Virgin Binder Subjected to RTFO and PAV versus Recovered Evotherm Binder Submitted to PAV



The implications of reduced binder oxidation extend beyond a mere explanation for the observed crack resistance. They also indicate that higher levels of RAP are possible in Evotherm mixes compared to HMA mixes. As RAP levels increase in a mix formulation, the stiffness of the overall binder does as well. Because the Evotherm binder is less stiff more RAP can be added without exceeding a maximum stiffness level, whether that stiffness is measured in penetration value, viscosity, or via DSR or BBR analyses.

Binder Analyses

VIII. *Analysis of Recovered Binder from High RAP Projects Shows that Evotherm WMA Enables the Use of Higher RAP Contents than HMA Due to Lower Binder Aging*

Sustainability objectives in this decade have compelled the North American asphalt industry to seek methods not only to use RAP but to increase the percentage of RAP used in asphaltic mixtures above current levels. Current usage levels vary from state to state, as recently reported by NCAT (12) at the RAP Expert Task Group Meeting on Oct. 28, 2008. Evotherm warm mix technology provides a means to higher RAP levels in a mix. Because the Evotherm mixes are less oxidized, higher proportions of RAP (with its aged binder) can be blended in than is possible with conventional HMA without exceeding stiffness levels required for good fatigue and cold fracture resistance.

The results of binder extraction and analysis in two projects in 2008 demonstrate this point. Missouri DOT chief materials engineer, Dale Williams, directed a study which aims to compare the field performance of Evotherm warm mix asphalt containing 20, 28, and 35% RAP to a conventional HMA containing 20% RAP (13). Test sections were laid on Route 44 in St. Louis, MO. These will be monitored for long-term performance. Additionally, loose plant mix was collected for each of the formulations. Binder from these mixes was extracted and analyzed via DSR. Table VIII-1 shows that the results of the Missouri DOT analysis. Most notable is the fact that the properties of the recovered binder from the HMA containing 20% RAP are virtually identical to the properties of the Evotherm mix formulated with 35% RAP.

TABLE VIII-1

Evotherm Technology Permits Use of Higher RAP Levels than Conventional HMA

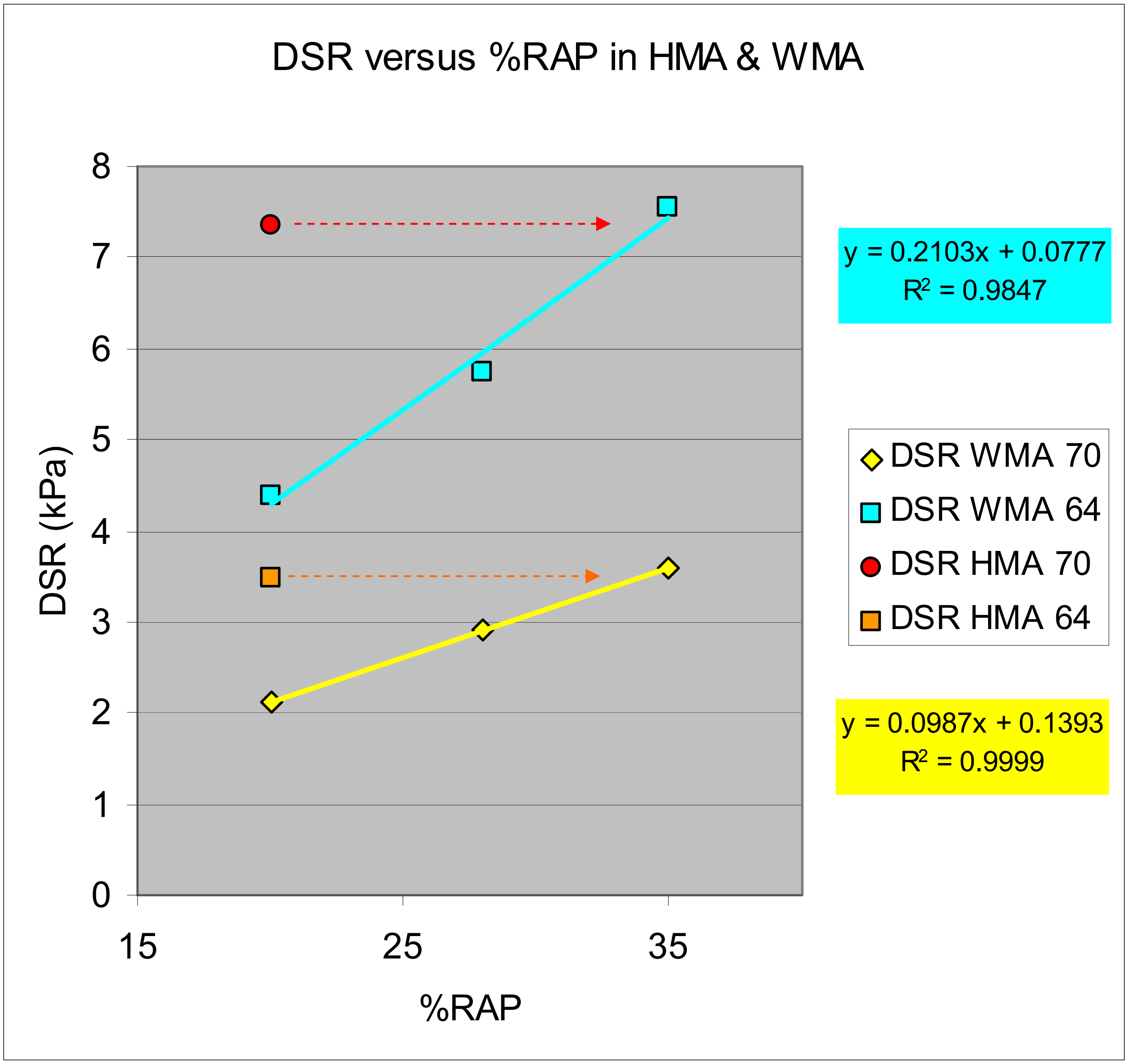
Property	Evotherm 20% RAP	Evotherm 28% RAP	**Evotherm 35% RAP**	**HMA Control 20% RAP**
Penetration	39	32	**28**	**29**
Viscosity	16,087	16,738	**23,470**	**25,920**
Ductility	79	54	**42**	**38**
DSR at 64°C	4.39	5.74	**7.56**	**7.35**
MSCR	42	37	**32**	**26**
DSR at 70°C	2.11	2.91	**3.59**	**3.48**
BBR at -12°C	0.437	0.406	**0.393**	**0.394**

The DSR results in Table VIII-1 at 64 and 70°C are presented graphically in Figure VIII-1. The incremental increase in RAP resulted in very consistent shifts in the rheological properties of the recovered binder. Moreover, one can see again in Figure VIII-1 the similarity in the DSR properties of the 20% RAP HMA and the 35% RAP Evotherm.

With the current inherent value of RAP at roughly \$35/ton (assuming RAP binder content 5%, asphalt price \$450/ton, and aggregate price \$13/ton), every percentage increase in RAP decreases the final mix price by \$0.35/ton. Thus, the Evotherm mix with 35% RAP would be \$5.25 per ton less expensive than the HMA with 20% RAP. It is important to note, this savings of \$5.25 does not include fuel cost reductions during the production of the Evotherm mix.

FIGURE VIII-2

DSR Trends with Evotherm Mixes Containing Increasing Levels of RAP



Another 2008 study examined the properties extracted from Evotherm and HMA mixes both containing 40% RAP. In this project, samples of the HMA control mix and the Evotherm warm mix were taken at the production facility. The binder was extracted from these mixes and tested. Table VIII-2 shows the results of these tests. The data clearly indicate that the use of Evotherm technology renders the binder much less oxidized than the binder in the HMA control mix. In this study, the Evotherm binder graded as a PG 76 on the upper temperature range, whereas the HMA control binder graded as a PG 82. Couple these results with the results of the Bending

Beam Rheometer (BBR) after pressure aging the binders, and one can see clearly that the Evotherm binder is demonstrably more resilient than the HMA control binder. The Evotherm low temperature grade is -22, whereas the HMA low-temperature grade failed the m-value specification at -22. The Evotherm binder would thus grade as a PG 76-22 and the HMA control binder would grade as a PG 82-16. This is arguably the most important result of these binder tests since, in a region like New York City where winters can be very severe, the resilient Evotherm binder will be better able to dissipate or relax the stresses that arise from thermal contraction of the pavement at low temperatures. In other words, by being better able to resist thermal cracking (cold fracture) the Evotherm pavement will last longer than the HMA control pavement.

It is noteworthy too that the HMA binder also failed the Pressure Aging Vessel (PAV) test. The specification of 5000 kPa maximum was established as an indication of resistance to fatigue cracking in the later stages of a pavement's service life. Evotherm pavement will show higher resistance to fatigue cracking. Taken together, these binder test data indicate that the Evotherm pavement will last longer.

TABLE VIII-2

Comparison of Extracted Binder from HMA Control Mix and Evotherm Warm Mix

Property	40% RAP HMA Control	40% RAP Evotherm WMA	Superpave Specification
Mix Production Temperature, °F	330	248	not applicable
Viscosity (Pa-s)	1.357	1.017	3 Pa-s max.
G*/sinδ at 64°C, kPa	9.60	5.31	not applicable to field binder samples
G*/sinδ at 70°C, kPa	4.54	2.59	
G*/sinδ at 76°C, kPa	2.18	1.27	
G*/sinδ at 82°C, kPa	1.08	0.642	
G*/sinδ at 88°C, kPa	0.56	-	
Penetration (dmm)	15	23	not applicable
BBR Stiffness (MPa)	222	158	300 MPa max
m-value	0.296	0.328	0.300 min
Pressure Aging Vessel G* x sinδ, kPa	5663	3218	5000 kPa max

Conclusions

The results of the laboratory and field studies disclosed herein demonstrate that Evotherm mixes can produce asphalt pavements with equal or greater durability than pavements constructed with conventional HMA technology. Less rutting should be expected as demonstrated in the NCAT pavement test track study and the Caltrans HVS evaluations, not to mention the numerous projects on actual heavy traffic routes in the U.S. Studies of the fracture resistance of lab-molded Evotherm field mixes showed that low temperature (thermal) cracking, overlay cracking, and fatigue cracking are substantially improved over those same properties in HMA mixes. Lastly, the explanation of these property improvements, which lead to increased durability, can be traced to advantages gained by using Evotherm technology to reduce production and construction temperatures.

The improvements in durability achievable with Evotherm technology mean that Evotherm pavements will last longer than pavements constructed with conventional hot mix asphalt. Taken together with benefits to the environment, human health, pavement constructability, the aforementioned durability improvements explain the action of states and other organizations, such as the FHWA, to propose specifications and guidelines for warm mix asphalt (14, 15).

References

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