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Warm Mix Asphalt Hits the Road

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By Larry Santucci, PE
Pavement Specialist, University of California Pavement Research Center, and California LTAP Field Engineer, Technology Transfer Program, Institute of Transportation Studies, UC Berkeley

The University of California Pavement Research Center

Using innovative research and sound engineering principles to improve pavement structures, materials, and technologies.

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Introduction

Warm Mix Asphalt (WMA) has the potential for being one of the most important breakthroughs for the asphalt industry in 50 years [1]. WMA was introduced in Europe in 1995 and debuted in the United States in 2004. In 2009, the National Asphalt Pavement Association (NAPA) estimated that within five years more than half of all asphalt mix produced nationwide will use warm mix processes. As of January 2010, at least 43 states had constructed trial sections using various WMA technologies (Figure 1).

Interest in WMA is far reaching [2, 3]. Hot mix producers are seeking energy efficient, environmentally sound, and worker friendly methods to produce asphalt mixes. Highway agencies are looking for ways to improve mix compaction, extend the construction season, permit longer haul distances, expand night paving, and use higher percentages of recycled mix. Air resources boards and environmental groups are seeking ways to reduce emissions during the production and transportation of asphalt mixes and the construction of asphalt pavements.

WMA reduces plant emissions.

WMA improves worker conditions.

What is WMA? Very simply, WMA technologies allow the mixing and placement of asphalt mix at temperatures significantly lower than those used with conventional hot mix asphalt (HMA). These technologies reduce the viscosity of the asphalt mix and provide complete aggregate coating at temperatures 35 to 100°F (20 to 55°C) lower than HMA.

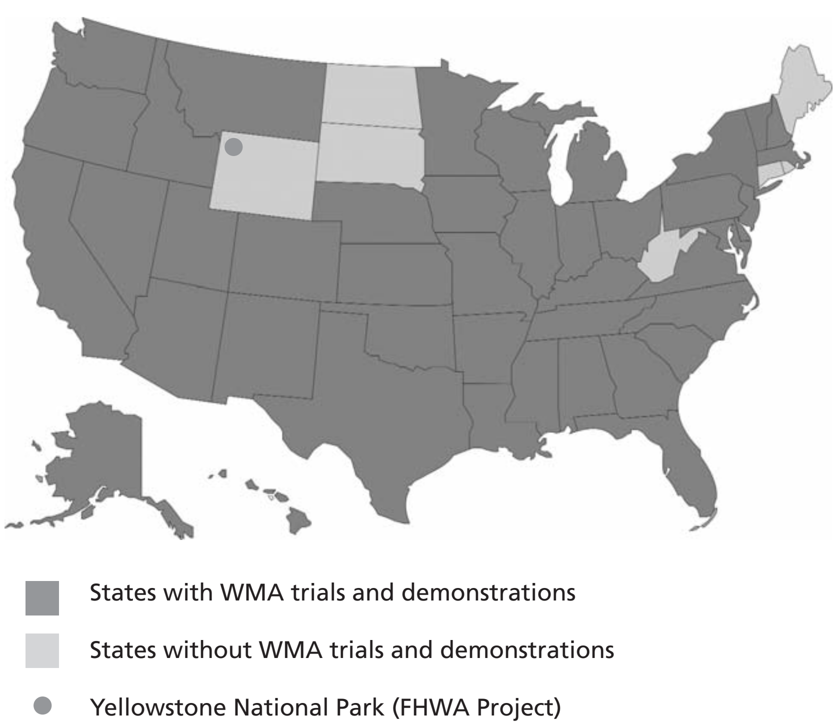
Benefits of WMA

The most obvious, and likely the most compelling, force leading to the development and implementation of WMA processes is energy conservation in the form of fuel savings. Burner fuel savings of 20 to 35 percent are possible [4]. These savings are dependent on the amount of mix temperature reduction, aggregate moisture content, and hot mix plant settings. The lower mixing temperatures associated with WMA result in lower emissions of volatile organic compounds, carbon monoxide, carbon dioxide, nitrogen oxides, and particulates.

WMA also reduces worker exposure to asphalt fumes at the plant and during the construction of the asphalt pavement. The improved workability of WMA at lower temperatures results in easier raking and compaction of the mix. Better compaction leads to higher in-place density, which reduces permeability and binder hardening due to aging, resulting in improved performance in terms of cracking resistance and moisture sensitivity. Paving can be completed with WMA under cooler conditions than those associated with normal HMA. Hence, WMA allows for an extended paving season, longer haul distance tolerance, and night paving operations.

Other benefits of WMA include the elimination of bumps when paving over rubber crack sealants (lower mat temperatures reduce the expansion of the sealant, which causes the bump), improved workability of polymer modified mixes, improved joint construction (warm mixes leave a more "vertical" joint than hotter mixes), and the ability to use greater amounts of reclaimed asphalt pavement (RAP).

FIGURE 1 **WMA trials and demonstrations as of January 2010**



SOURCE: FEDERAL HIGHWAY ADMINISTRATION

WMA: The European Influence

WMA appeared on the scene in Europe around 1995 primarily in response to concerns associated with the production of hot mix, including environmental impacts, energy use, and worker conditions.

In 2002, NAPA conducted a study tour of Europe to investigate WMA technologies. As a result, interest in WMA technologies grew in the United States. The Federal Highway Administration (FHWA) designated WMA as a focus area. A WMA Technical Working Group was formed to oversee WMA developments and field trials in the United States. The National Center for Asphalt Technology (NCAT) and several universities conducted laboratory investigations of WMA and a number of state highway agencies began to place field trials of WMA.

In 2007, a team of 13 asphalt paving technologists from the United States participated in a second tour, referred to as a scanning tour, of four European countries—Belgium, France, Germany, and Norway—to evaluate various WMA technologies. The team included representatives of the American Association of State Highway and Transportation Officials (AASHTO), FHWA, NAPA, the Asphalt Institute, asphalt suppliers, HMA contractors, and a consultant.

Based on its observations, interviews, and expertise, the team concluded that there are no long-term barriers to WMA use in the United States. In a comprehensive report on the scanning study [5], the team

TABLE 1 WMA Technologies

Product / Process	Supplier	Web Address
Wax Additives		
Asphaltan B	Romonta GmbH (Germany)	www.romonta.de
Sasobit	Sasol Wax (South Africa)	www.sasobit.com
Chemical Modifiers		
CECABASE RT	Arkema Group (France)	www.cecachemicals.com
Evotherm	MeadWestvaco Asphalt Innovations (USA)	www.evotherm.com
Rediset WMX	Akzo Nobel N.V. (The Netherlands)	www.surfactants.akzonobel.com
Foaming Processes		
Advera WMA	PQ Corporation (USA)	www.adverawma.com
AQUABlack	Maxam Equipment, Inc. (USA)	www.maxamequipment.com
Aspha-Min	Eurovia Services GmbH (Germany)	www.aspha-min.com
Double Barrel Green	Astec Industries (USA)	www.astecindustries.com
Low Emission Asphalt (LEA)	Suit-Kote (McConnaughhay) Corporation (USA)	www.lowemissionasphalt.com
Terex WMA	Terex Corporation (USA)	www.terexrb.com
Ultrafoam GX	Gencor Industries, Inc. (USA)	www.gencorgreenmachine.com
WAM-Foam	Shell International (UK)/Kolo-Veidekke (Norway)	www.shell.com/bitumen

identified the following implementation goals to encourage the adoption of the WMA concept in the United States:

- WMA should be an acceptable alternative to HMA at the contractor's discretion if the WMA meets applicable HMA specifications.
- Approval of WMA should be based on performance testing and supported by successful field trials.
- Best practices should be implemented during WMA production for handling and storing aggregates to minimize moisture content. Burner adjustments and plant settings also need to be optimized to handle WMA.
- WMA field trials involving heavy traffic and sufficient tonnage to provide a representative sample of mix should be encouraged. Field trials should include an HMA "control" section and highway agencies should commit to monitor performance for a minimum of 3 years.

WMA Technologies

WMA technologies can be grouped into three general categories [4, 6]:

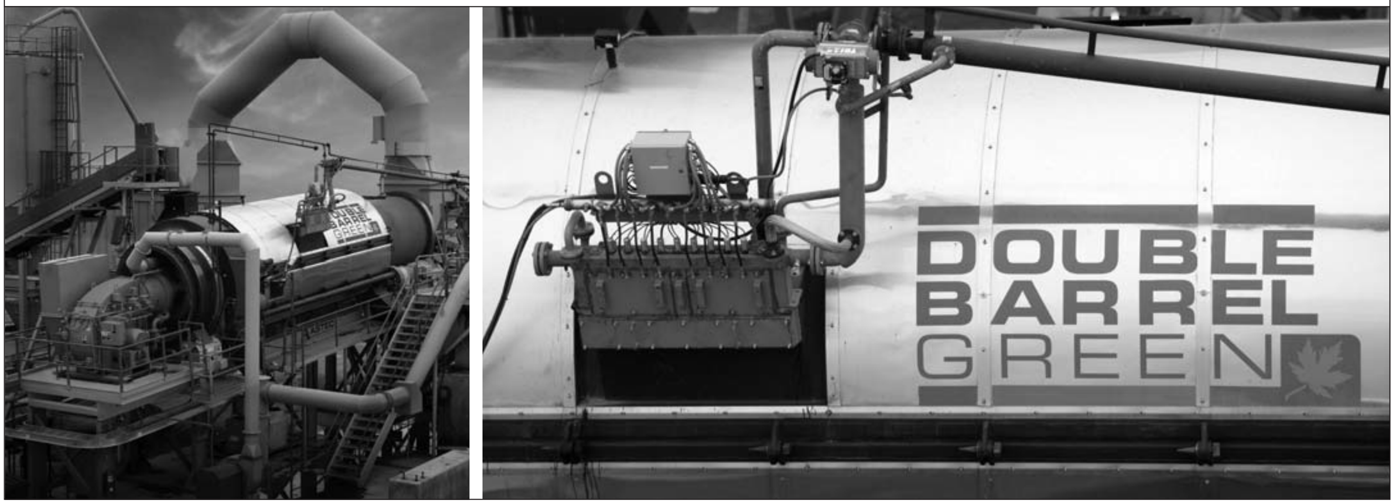
- Those that use wax-based additives
- Those that use chemical modifiers or surfactants
- Those that use water to promote foaming (chemical or mechanical)

The WMA processes that use wax additives show a significant drop in binder viscosity above the melting point of the additive, resulting in mixing and coating of aggregates at temperatures lower than those used with conventional HMA. The processes that use chemical modifiers depend on chemical reactions to promote coating, adhesion, and workability of the mix at reduced temperatures. The processes that use water rely on a volume expansion from the conversion of liquid to steam to cause an expansion of the asphalt binder and a decrease in mix viscosity. Water is introduced to the mix through a foaming operation using a material containing internal water, such as a zeolite, or through the use of moist fractions of the aggregate.

There are currently at least 20 competing warm mix technologies on the market. Some WMA processes are not used in the United States. Additional suppliers are likely to enter the market in the future as new additives or equipment innovations are developed. The following summary represents a sampling of the more common WMA products and processes used at the publication date of this article. More detailed information can be found in references 4 through 7 and on the websites noted in Table 1.

Advera WMA is a product developed by PQ Corporation (Malvern, PA). The Advera WMA system uses a synthetic zeolite, which contains encapsulated water, to produce a sustained, time-release foaming of the asphalt binder in the mix. The water is released when the zeolite contacts the heated asphalt binder and generates a foaming action. The micro-foam created enhances mix workability until the temperature drops below about 212°F (100°C). Advera WMA does not alter the performance grade of the asphalt binder.

FIGURE 2 Astec Double Barrel Green System



SOURCE: ASTEC INDUSTRIES

PQ Corporation recommends 0.25 percent Advera WMA by mass of mix (5 pounds per ton). Production and placement temperatures are typically 50 to 70°F (28 to 39°C) lower than conventional HMA. Advera WMA has been used with dense and open graded mixes as well as in base and wearing courses throughout the United States and Canada.

The **AQUABlack** WMA system was developed by Maxam Equipment, Inc. (Kansas City, MO). The AQUABlack system is designed as a plug-in system that can be retrofitted to any plant. The stainless steel AQUABlack foaming unit creates, mixes, and entrains micro-bubbles into the asphalt binder via a series of high pressure jets, a compression nozzle, and a static mixing chamber. The micro-bubbles alter the asphalt binder's physical characteristics until compaction of the mix is complete.

Asphaltan B is a product of Romonta GmbH (Germany). It is currently not used in the United States. Asphaltan B is a mixture of substances based on Montan wax components and higher molecular weight hydrocarbons that was developed specifically for "rolled asphalt" mixes. Montan wax is found in Germany, Eastern Europe, and parts of the United States in certain types of lignite or brown coal deposits. Romonta recommends adding Asphaltan B at 2 to 4 percent by mass of binder. It can be added at the mix plant or directly to the asphalt at the asphalt plant. The melting point of Asphaltan B is about 210°F (99°C). Asphaltan B acts as an asphalt flow improver that results in reduced mix production temperatures. The reduced binder viscosity also aids mix compaction. At service temperatures below the melting point of Asphaltan B, the mix exhibits good resistance to rutting.

Aspha-Min is a product of Eurovia Services GmbH (Germany). Aspha-Min is a synthetic zeolite (sodium aluminum silicate). The zeolite contains 21 percent water by mass, which is released in the temperature range of 185 to 360°F (85 to 182°C). Once added to the asphalt mix, the released water creates a volume expansion of the binder, resulting in asphalt foam that improves mix workability and aggregate coating at lower temperatures. Eurovia recommends a rate of 0.3 percent Aspha-Min by mass of mix, which will lower asphalt mix production temperatures by about 54°F (30°C) and result in a 30 percent savings in fuel use.

CECABASE RT is a product of CECA Chemicals, a subsidiary of the Arkema Group (France). CECA is a European leader in emulsifiers and adhesion agents for asphalt. CECA claims that its CECABASE RT additives used in WMA can reduce the application temperature on the road surface by as much as 122°F (50°C) with no adverse effect on performance of the asphalt mix. The additives are added directly to the asphalt at a rate of 0.2 to 0.4 percent by mass of binder. When compared to conventional HMA, CECA indicates that the use of these chemical modifiers can reduce energy consumption and gas emissions by 20 to 50 percent and reduce dust emissions by 90 percent.

Astec Industries (Chattanooga, TN) introduced the **Double Barrel Green System** in 2007 as an option with a new Double Barrel drum mixer or as a retrofit to an existing Double Barrel mixer. Astec also introduced the Green Pac warm mix system, which can be retrofitted to any continuous or batch mix plant. The system, shown in Figure 2, injects water along with the asphalt binder to produce foamed WMA. The foamed asphalt effectively coats the aggregate at lower mixing temperatures. Fuel savings of roughly 14 percent have been achieved with the Double Barrel Green System.

Evotherm is a product of MeadWestvaco Asphalt Innovations (Charleston, SC). Evotherm uses a chemical additive that is injected into the asphalt line just before mixing for drum plants or directly into the pug-mill of a batch plant. The Evotherm chemical package and dispersed asphalt technology enhance aggregate coating, adhesion, and workability of the mix at reduced temperatures. MeadWestvaco claims that asphalt mixes can be produced at temperatures 100°F (56°C) lower than conventional HMA using its WMA technology. Other benefits of this significantly lower production temperature include greater reductions in emissions and energy consumption than reported for some other warm mix systems. Evotherm was used on over 300 projects in 25 states and in France, Spain, Canada, South Africa, and China.

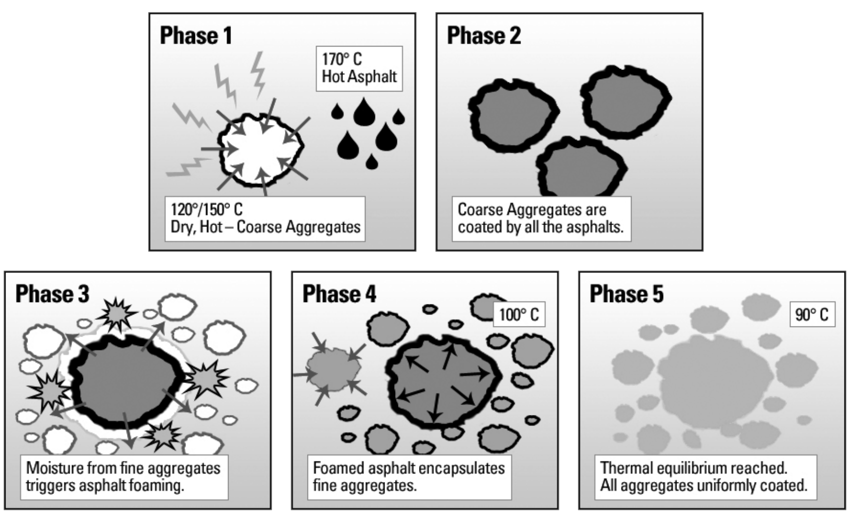
Low Emission Asphalt (LEA) is a warm mix technology offered by Suit-Kote Corporation (Cortland, NY). Suit-Kote acquired McConnaughhay Technologies, a company with a long history of emulsion mix technology and innovation, in 1991. LEA is based on the Low Energy Process (Figure 3) developed in France and involves the use of a chemical additive and sequential mixing. The liquid chemical additive is added to the asphalt binder at a rate of 0.5 percent by mass of binder prior to coating hot coarse aggregates. Unheated wet sand is then introduced, creating a foaming action. The wet sand fraction could be as high as 40 percent of the total mix and contain 0 to 100 percent RAP. Mix production temperatures using the LEA process are about 210°F (99°C) and placement temperatures can be as low as 170°F (77°C). The LEA process can be used with both drum and batch plants as long as a RAP delivery system is available to handle the unheated sand fraction. Several LEA projects have been placed across New York State since 2006.

Rediset WMX is a product of Akzo Nobel N.V. (The Netherlands). Rediset WMX is described as a chemical modifier formulated with a blend of surfactants and antistripping agents. Rediset WMX comes in a pastille (i.e., bead) form (Figure 4) that can be added to the asphalt binder or directly to the mixing unit at a rate of 1.5 to 2 percent by mass of binder. It does not change the PG grade of the asphalt. Mix production temperatures are reduced by 40 to 60°F (22 to 33°C) and paving temperatures by 70 to 140°F (39 to 78°C) using the Rediset system. The adhesive properties of Rediset WMX may eliminate the need for separate treatments of liquid antistrip or lime. Hamburg Wheel Tracking Tests show mixes containing Rediset WMX have rutting resistance comparable to mixes treated with hydrated lime.

FIGURE 4
Rediset WMX additive in pastille form

SOURCE: AKZO NOBEL N.V.

FIGURE 3 **Low energy process used in Low Emission Asphalt (LEA)**



The LEA Process is a patented process and a chemical additive is required.

SOURCE: MCCONNAUGHAY TECHNOLOGIES AND LEA-CO

Sasobit is a product of Sasol Wax (South Africa). Sasobit is a fine crystalline, aliphatic hydrocarbon produced from coal gasification using the Fischer-Tropsch (FT) process and is often referred to as an FT paraffin wax. FT waxes have a much longer chain length than naturally occurring bituminous paraffin waxes. Sasobit is described as a modifier or asphalt flow improver. It comes in either flake or pellet form (Figure 5). Sasobit is completely soluble in the asphalt binder at temperatures above 240°F (116°C). The resultant drop in binder viscosity enables asphalt mix temperatures to be reduced by 18 to 54°F (10 to 30°C) and aids in the ease of compaction or "compactibility" of the mix. Sasobit forms a

FIGURE 5
Sasobit additive pellets

SOURCE: HURLEY AND PROWELL [11]

lattice structure in the asphalt binder below 210°F (99°C), which helps provide mix stability and resistance to rutting at normal pavement service temperatures. Sasobit is added at rates of 1 to 2.5 percent by mass of binder with rates of 1 to 1.5 percent typically used in the United States. Addition rates over 3 percent can adversely impact the low temperature properties of the mix.

The **Terex WMA** system, developed by the Terex Roadbuilding Division of Terex Corporation (Westport, CT), is based on field-proven foamed asphalt technology, originally pioneered in 1998. The Terex system uses a single expansion chamber, which ensures a consistent asphalt/water mix at any production rate. The foamed asphalt is produced outside of the drum mixer and immediately injected into the mixing chamber to provide an even coating of the aggregate. The Terex system can be easily adapted to most existing drum mix plants to produce WMA. Terex claims mix production temperatures can be reduced by up to 90°F (32°C) without the use of additives.

Gencor Industries, Inc. (Orlando, FL) developed the **Ultrafoam GX** system to produce WMA using foamed asphalt technology. The Ultrafoam GX system uses a special foaming generator, dubbed the Green Machine, that can be easily connected to an existing asphalt injection line going to a drum mixer. The Ultrafoam GX system mixes asphalt and water together in a proportionate and continuous fashion and generates small, evenly sized bubbles, which result in consistent foaming at all production rates.

WAM-Foam was jointly developed by Shell International Petroleum Ltd. (United Kingdom) and Kolo-Veidekke (Norway). The binder in WAM-Foam is formed by using two separate components: a soft binder and a hard binder in foam form. The soft binder is mixed with the aggregate at approximately 230°F (110°C) to achieve full aggregate coating. The hard binder is then added to the pre-coated aggregate as foam. The hard binder foam combines with the soft binder to produce the desired final asphalt properties. Shell states that the initial coating of the aggregate is critical in order to prevent water from reaching the binder-aggregate interface, which could result in moisture sensitivity issues for the asphalt mix. Shell reports that the reduced production temperatures using this process can lead to fuel savings and CO_2 emission reductions of 30 percent.

Selecting a WMA Technology

Mix producers must consider several factors when selecting a WMA technology. The amount of WMA the plant intends to produce is an important consideration in determining how much to invest. Some WMA technologies (e.g., mechanical foaming) require higher initial equipment costs. Others use additives that can drive up the cost per ton of mix produced. Some technologies offer greater temperature reductions than others and some WMA additives can slightly raise the high-temperature and low-temperature grades of the PG binder. These issues need to be considered in light of the fuel savings, environmental benefits, and worker-exposure benefits associated with WMA. Trends indicate that many state, county, and city departments of transportation will allow WMA as a contractor option provided the technology is on an "approved list." Some authorities are beginning to demand the use of WMA instead of HMA. Many paving contractors are also encouraging asphalt mix producers to use WMA technologies because of the worker-exposure and workability advantages.

WMA Research in California

Research in California has focused on answering the question "Does the use of additives to reduce the production and construction temperatures of HMA influence performance of the mix?" To answer this question, the California Department of Transportation (Caltrans) and the University of California Pavement Research Center (UCPRC) are conducting a comprehensive phased study, which includes accelerated pavement testing (APT) on two test tracks constructed with dense graded HMA and rubberized gap graded (RHMA-G) mixes respectively, laboratory testing of specimens removed from the test tracks, and monitoring of experiments constructed with a range of different mixes on state highways. The first test track was constructed at the Graniterock Asphalt Plant in Aromas, CA, and the second at the UCPRC facility in Davis, CA. All laboratory testing was carried out at the UCPRC laboratory in Richmond, CA.

Accelerated Pavement Testing and Laboratory Testing

The first two phases of the APT study on dense graded HMA have been completed [8] and the third phase on rubberized mixes is currently underway. Both studies included monitoring the production of the mixes and construction of the test tracks. The Graniterock test track included an HMA control and three WMA technologies (Advera WMA, Evotherm, and Sasobit), while the Davis test track has two RHMA-G controls and seven WMA technologies (Advera WMA, Double Barrel Green, CECABASE RT, Evotherm, Ultrafoam GX, Rediset WMX, and Sasobit). In the first phase, a Heavy Vehicle Simulator (HVS), shown in Figure 6, evaluated early rutting performance and laboratory tests assessed rutting, fatigue performance, and moisture sensitivity. The second phase of the study focused on moisture sensitivity testing with the HVS and some additional laboratory testing. The pavement structural section and test track layout for HVS testing are shown in Figures 7 and 8.

Key observations and conclusions from the study on dense graded mixes include:[1]

Mix design. The study used a standard Graniterock mix design that meets specifications for a Caltrans 19mm Coarse Type-A Asphalt Concrete. The Hveem mix design was not adjusted to accommodate the warm mix additives. The suppliers determined additive application rates, which were as follows: Advera WMA, 4.8 percent by mass of binder (0.25 percent by mass of mix); Evotherm, 0.5 percent by mass of binder; and Sasobit, 1.5 percent by mass of binder. The binder content of the Sasobit mix was 0.72 percent below the target binder content of 5.2 percent by mass of aggregate recommended from the Hveem design due to a control system problem. The asphalt binder supplied to the project was a PG 64-16 that graded out as a PG 64-22. The binder grade changed from a PG 64-22 to PG 70-22 after mixing Sasobit with the base asphalt. The addition of Advera WMA and Evotherm did not alter the PG grade.

Mix production. Only minor asphalt plant modifications were needed to accommodate the WMA additives. No unusual problems were encountered during production of the WMA mixes at lower temperatures. Moisture contents of the WMA mixes, although within Caltrans limits [9], were higher than the HMA control, suggesting that less moisture evaporates from the aggregate at the lower production temperatures. **Controlling aggregate moisture contents in stockpiles and prior to mix production will be critical for the successful implementation of WMA technologies.**

FIGURE 6
Heavy Vehicle Simulator (HVS) used in accelerated pavement testing of WMA sections

SOURCE: UNIVERSITY OF CALIFORNIA PAVEMENT RESEARCH CENTER

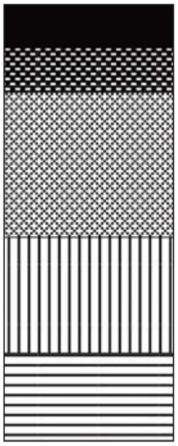
[1] No results were available from the rubberized asphalt study at the time this article was prepared.

Construction. Construction procedures and pavement quality were not affected by the lower construction temperatures. Although the Evotherm and Sasobit sections exhibited some tenderness during rolling, the paving crew did not consider it significantly different from that experienced with conventional HMA during normal paving operations. Tenderness on the Evotherm and Sasobit sections was attributed to the fixed production temperatures set for the experiment. Slightly lower production and paving temperatures would have eliminated this problem. The paving crew did, however, comment on the improved working conditions in terms of lower temperatures, improved workability (raking), and reduced odors. Some smoke was observed on the HMA control during transfer from the truck to the paver. There was no smoke associated with the WMA materials. **It should be noted that optimal production and placement temperatures will differ between the different WMA technologies.**

Laboratory results. Laboratory shear and fatigue tests indicated that the WMA technologies examined in this study will not adversely affect the rutting and fatigue performance of mixes. Laboratory moisture sensitivity testing showed that all the mixes, including the control, were potentially susceptible to moisture damage. Therefore, additional HVS testing was proposed to examine moisture sensitivity issues under full-scale loading conditions.

Test track results. Skid resistance tests showed that the WMA additives did not influence the skid resistance of the final pavement sections. In the first phase of HVS rut testing, the rutting rates (number of HVS repetitions required to obtain an average maximum rut depth of 0.5 inches (12.5 mm)) on the Advera WMA and Evotherm sections were slightly higher than the HMA control. The early embedment phase (traffic consolidation) was slightly higher on these two sections, which was attributed to less binder oxidation during mix production at lower temperatures.

FIGURE 7 Pavement structure for WMA test sections



Layer:	**DGAC**
Thickness:	2 x 60 mm = 120 mm (4.7 in)
Modulus:	1,000 MPa (145,000 psi)
Layer:	**Imported Class 2 Aggregate Base-Course**
Thickness:	300 mm (12 in)
Modulus:	150 MPa (21,750 psi)
Layer:	**Existing Subbase**
Thickness:	250 mm (10 in)
Modulus:	400 MPa (58,000 psi)
Layer:	**Bedrock**
Thickness:	Semi-infinite
Modulus:	>3,000 MPa (> 435,000 psi)

SOURCE: UNIVERSITY OF CALIFORNIA PAVEMENT RESEARCH CENTER

After this initial embedment, the behavior of all three sections was almost identical. The rutting rate on the Sasobit section was much slower, which was attributed to the lower binder content. In the second series of tests, conducted 12 months after construction, water was continually applied to the test sections while HVS testing was conducted. Results from these tests indicate that externally applied moisture was not detrimental to the performance of the WMA sections, with all WMA sections providing equal or better performance in terms of rutting rate than the HMA control.

The HVS and laboratory testing completed in this study suggest that the three WMA technologies assessed can be used in California. The researchers recommended that the assessment of WMA technologies should be continued in full-scale pilot studies on in-service pavements.

Additional WMA Research

NCAT has evaluated three WMA technologies in the laboratory [10, 11, 12]. This initial research focused on the Aspha-Min, Sasobit, and Evotherm technologies. Conclusions from these studies show several trends. The addition of either Aspha-Min, Sasobit, or Evotherm lowered the measured air voids and improved the compactability of mixes when using gyratory or vibratory compaction. Improved compaction was noted at temperatures as low as 190°F (88°C). The addition of Evotherm increased the resilient modulus (M_r) of mixes compared to the control mix with the same PG binder while the Aspha-Min and Sasobit additives did not appear to affect the resilient modulus of the mix. The rutting potential of mixes with all three additives increased with decreasing mixing and compaction temperatures, which may be related to the decreased aging of the binder. Lower production temperatures associated with WMA may increase the potential for moisture damage as a result of incomplete drying of the aggregate. The use of liquid anti-stripping agents or hydrated lime may be necessary to mitigate the potential for moisture damage.

The National Cooperative Highway Research Program (NCHRP) has two major research projects on WMA underway. The objective of NCHRP Project 09-43 "Mix Design Practices for Warm Mix Asphalt Technologies" is to develop a performance based mix design procedure for WMA in the form of a manual of practice. The objectives of NCHRP Project 09-47 "Engineering Properties, Emissions, and Field Performance of Warm Mix Asphalt Technologies" are to (1) establish relationships among engineering properties of WMA binders and mixes and the field performance of pavements constructed with WMA technologies, (2) determine relative measures of performance between WMA and conventional HMA pavements, (3) compare production and laydown practices and costs between WMA and HMA pavements, and (4) provide relative emissions measurement of WMA technologies as compared to conventional HMA technologies. A third project, NCHRP 09-49, "Performance of WMA Technologies: Stage 1-Moisture Susceptibility," is in the proposal evaluation stage and likely to be underway by the end of calendar year 2010.

NAPA and FHWA created a WMA Technical Working Group whose mission is to evaluate and validate WMA technologies and to implement WMA policies, practices, and procedures to contribute to a high quality, cost effective asphalt pavement system.[2] The FHWA Office of Pavement Technology has also activated a Mobile Asphalt Mixture Testing Laboratory (MAMTL) to advance WMA research and validation through material sampling and performance testing. The MAMTL has been on site at many of the WMA projects across the country.

WMA Concerns

Despite the numerous benefits associated with WMA, there are some concerns that should be addressed prior to the inevitable adoption and implementation of WMA technologies. Most researchers and paving engineers are aware of these potential limitations and are developing procedures to minimize their impact. One concern is moisture sensitivity of warm mixes produced with aggregates that are not adequately

2. Useful information on the activities of the WMA Technical Working Group and the status of implementation of WMA technologies can be found at *www.warmmixasphalt.org.*

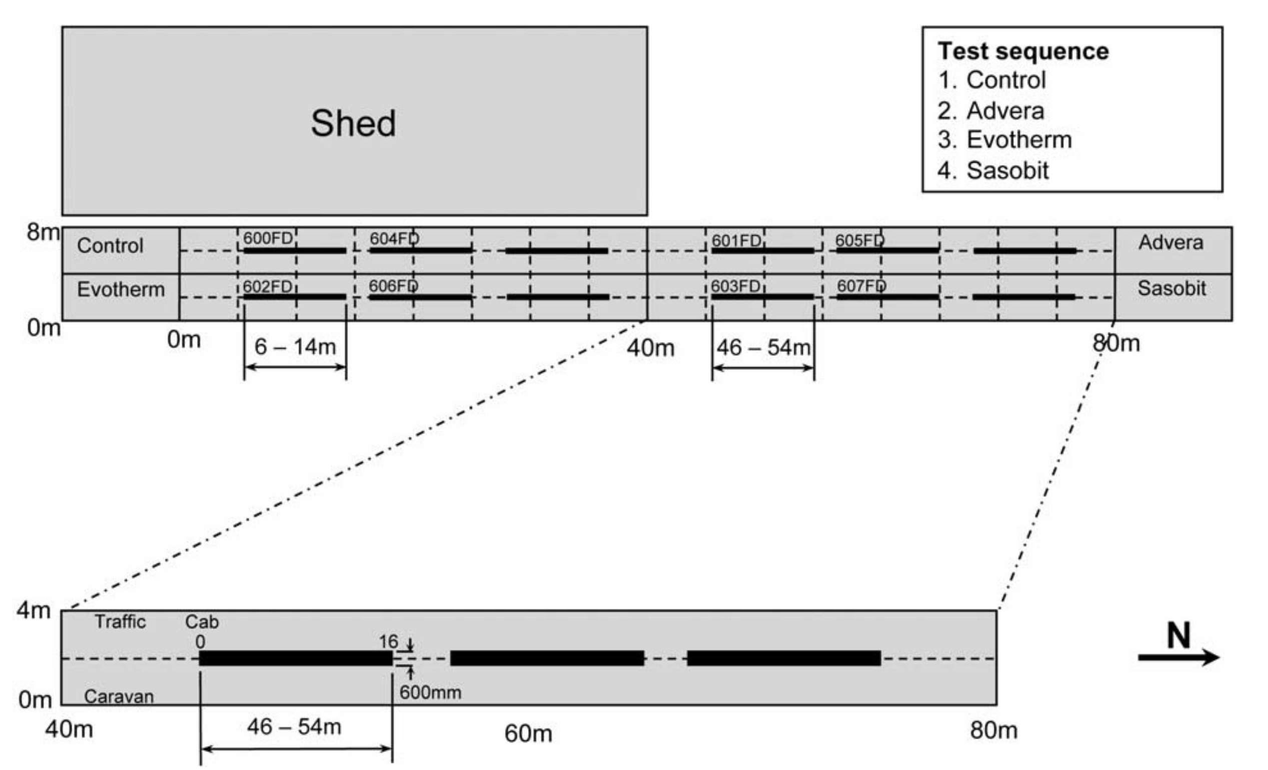
dried at lower mix production temperatures. During the FHWA scanning tour, European researchers continually pointed out the importance of controlling moisture levels in aggregates used in WMA. This could mean that actively monitoring and/or providing covered storage for aggregate stockpiles is needed to keep moisture content low.

Another concern associated with lower mix production temperatures is the effect that less binder hardening during the mixing process can have on the early rutting potential of the pavement. This effect can likely be offset by the improved compaction achievable with WMA technologies. Better fatigue performance may also result from this effect. A minor issue to be aware of is the effect wax additives may have on the low temperature cracking resistance of a mix. The addition of wax to asphalt could alter the lower end of a PG binder, for example, from a PG 64-28 grade to a PG 64-22 grade. Again, this is not an insurmountable problem but one that designers need to account for in selecting the base asphalt for WMA modification. Suppliers of wax additives are aware of this limitation and are actively working on a solution involving a low temperature grade change in the opposite direction. To date, there have been no reported low temperature performance problems associated with WMA technologies that use wax additives.

Compaction of WMA

One of the most important benefits of WMA may well be the compactability of mixes at temperatures lower than those required with HMA. Compaction levels of 94 to 95 percent maximum theoretical density (MTD) have been reported on WMA projects [13]. In some instances, mixes compacted so well that contractors were able to pull a roller out of the paving train. However, it remains important to compact until rock-to-rock contact is achieved for good rut resistance. Better joint construction also appears to result from the improved compactability and workability of WMA. The NCAT laboratory studies discussed earlier showed an average reduction in air voids of 0.65 to 1.4 percent, depending on which WMA additive was being evaluated, in mixes compacted in the gyratory and/or vibratory compactor. This ability to improve compaction using WMA technologies may provide the asphalt industry an opportunity to further enhance pavement quality and enhance long-term performance.

FIGURE 8 Test track layout and HVS test pattern for WMA study

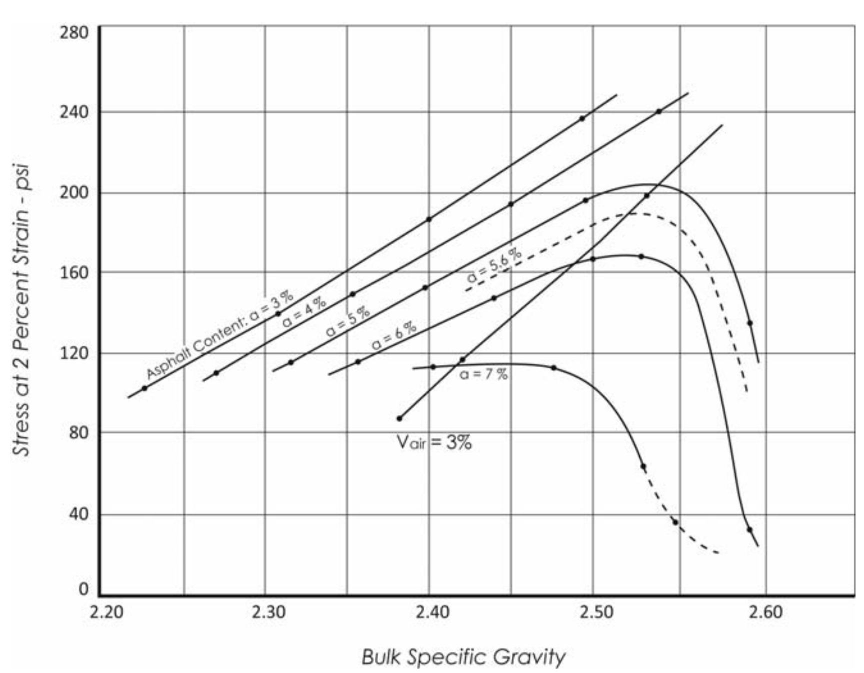


SOURCE: UNIVERSITY OF CALIFORNIA PAVEMENT RESEARCH CENTER

Caltrans currently requires a compaction range of 91 to 97 percent MTD for dense graded asphalt mixes used on standard construction projects (92 to 96 percent MTD for QC/QA projects) [9]. Penalties can be assessed when compaction levels fall below or above these limits. Raising the lower limit from 91 to 93 percent MTD can significantly improve the fatigue and rut resistance of an asphalt pavement. Harvey et al [14] identified with laboratory tests the major impact air void content has on the fatigue resistance and stiffness (rut resistance) of dense graded asphalt mixes used in California. These findings were later verified in full scale HVS tests on asphalt pavement sections [15]. More recently, Blankenship [16] has shown in laboratory tests on Kentucky dense graded mixes that a 1.5 percent reduction in air voids (91.5 to 93 percent MTD) can increase mix fatigue life 4 to 10 percent and increase rut resistance 34 percent. Reduced air voids in the mix can also improve the long-term durability of the pavement by limiting oxidative hardening of the asphalt binder. In addition, lower mix permeability, which is associated with lower air voids, can improve the moisture resistance and reduce the aging of the pavement.

It appears that WMA technologies allow us to easily achieve a slightly higher minimum compaction level. Actually, the greater challenge may be at the upper compaction limit where the possibility of over-compaction exists. Paving contractors need to realize, especially with WMA, that exceeding this upper limit can result in rutting or permanent deformation failures under traffic. This potential situation is illustrated in Figure 9 [17] where a major drop-off in mix stability occurs at roughly the 3 percent (97 percent MTD) level.

FIGURE 9 **Effect of over-compaction on asphalt mix stability**



SOURCE: MONISMITH AND VALLERGA [17]

When a mix compacts too easily, the solution is normally not to reduce the compactive effort, but to adjust the physical characteristics of the aggregate and/or the aggregate gradation.

Field Performance

As seen in Figure 1, most states had participated in field projects to evaluate the production, construction, and performance of WMA by early 2010. The following represents a sampling of the experiences with WMA in three states: California, Texas, and Pennsylvania [13, 18, 19].

California. Caltrans focused on using WMA technologies to help address challenging situations such as night paving, cool temperature applications (coastal regions), and projects that involve long haul distances. The use of WMA with open graded friction courses (OGFC) and rubberized asphalt mixes (RHMA) was of particular interest. Caltrans initiated field evaluations of WMA in 2006 and reported on 7 projects placed through 2008 [20]. Additional projects were placed in 2009 and others are planned for 2010.

There have also been several local agency WMA jobs placed in California. The first WMA project for Caltrans was a 200 ton shoulder overlay on Route 152 in Santa Clara, CA, using a gap graded rubberized asphalt mix (RHMA-G). The project involved night paving and a 30 minute haul. The Sasobit additive used resulted in a 40°F (22°C) drop in mix production temperature from 320°F (160°C) to 280°F (138°C). The job is performing well after 2 years. The next project was on Interstate 70 in Oroville, CA, where 1,400 tons of a dense graded WMA was produced using Evotherm. The plant mix temperature was about 240°F (116°C) and breakdown rolling was carried out between 183°F (84°) and 215°F (102°C). The road was opened to traffic three hours after placement with no signs of rutting.

The first major WMA demonstration project for Caltrans was on Highway 1 near Morro Bay, CA, in May 2008 where a control section and three WMA sections were placed. The WMA technologies selected were Advera WMA, Evotherm, and Sasobit. The mix was a PG 58-34 polymer modified OGFC. Mix temperatures were lowered by 50°F (28°C) and compaction temperatures were lowered by at least 30°F (17°C) with the warm mix processes. All the WMA systems improved the workability of the polymer modified OGFC. It was also obvious from this project that certain plant adjustments needed to be made to assure consistency and uniformity of the product delivered to the placement site.

The next series of WMA projects were on the coastal region of northern California on Route 1 in Mendocino, CA; Highway 200 in McKinleyville, CA; and Route 1 in Point Arena, CA. All three projects involved long haul distances and cool coastal temperatures. WMA additives Sasobit and Evotherm were used with dense graded and OGFC mixes. In the Fall of 2008, a 1,000 ton WMA job was placed on Interstate 5 in the central valley of California near Los Banos, CA, using Double Barrel Green and Evotherm technologies. In 2009, Caltrans constructed several large WMA projects including a 15,000 ton open graded rubberized asphalt mix (RHMA-O) job on Interstate 5 near Orland, CA; a 9,000 ton RHMA-O night paving job on Highway 70 near Marysville, CA; and a 2,500 ton RHMA-G job on Highway 101 near Rio Dell, CA.

Caltrans will continue to monitor the performance of these projects and evaluate additional WMA projects constructed in 2010. Caltrans is currently formulating procedures to allow the use of approved WMA technologies in California as a contractor alternative to conventional HMA.

Texas. In late 2009, it was estimated that over 1 million tons of WMA had been placed and another 1 million tons were under contract in Texas. The Texas DOT has used so much WMA that it no longer tracks quantities and now routinely allows the use of WMA as a contractor option. The Young County, TX, project, placed in 2008, was a 69,000 ton job on State Highway 251 and US 380 that used a standard 3/8-inch maximum aggregate Texas DOT mix. The Double Barrel Green system was used to produce the WMA. The mix production temperature of 270°F (132°C) was about 50°F (28°C) lower than that used with conventional HMA and resulted in 18 percent savings in burner fuel costs. Placement temperatures ranged between 220°F (105°C) and 250°F (122°C). Results from this project were very positive. The Double Barrel Green process was also used on a 36,000 ton job in 2008 on US 183 in Throckmorton County, TX. This warm mix job used 20 percent RAP. A third example involving WMA technology was a 50,000 ton job constructed in 2008 on Business Route 287, northwest of Fort Worth, TX, where about 20 percent RAP was used in the mix. The paving process on this project went very smoothly and compaction was easily achieved with only 4 roller passes rather than the roughly 20 passes normally required with conventional HMA. These results indicate that better compaction can be achieved using WMA technology.

Pennsylvania. The Pennsylvania DOT set a goal of using WMA technologies on 20 percent of its total 2009 asphalt tonnage. A District 2 trial project constructed in May through June 2009 used four WMA technologies—Advera WMA, Sasobit, Low Emission Asphalt (LEA), and the Ultrafoam GX process. Despite low ambient temperatures at the plant in the 30°F (~0°C) range, the contractor was able to obtain 92 to 93 percent MTD during compaction of the mix at the job site. Evotherm was used to produce WMA on another project in Carlisle, PA. The mix contained about 15 percent RAP. The compaction process resulted in a 94 to 95 percent MTD in the finished pavement.

Summary

The WMA revolution is sweeping across the country. Originally introduced in Europe, most highway agencies and major contractors throughout the United States are now evaluating WMA. The benefits of WMA, such as lower fuel costs and lower emissions at the mix plant, less worker exposure to asphalt fumes, and improved workability of the mix during compaction, far outweigh the potential concerns of partially dried aggregates leading to moisture sensitivity problems, reduced binder hardening resulting in early rutting distress, and some additives affecting low temperature cracking resistance. These concerns can be alleviated with good aggregate storage practices, careful adjustments to plant settings, and proper selection of asphalt binders.

The roughly 20 WMA technologies available can be grouped into three categories: those that use wax-based additives; those that use chemical modifiers or surfactants; and those that introduce water in some manner to generate foaming. The selection of a particular product or process depends heavily on the anticipated market demand for WMA. Required temperature reductions, equipment costs, additive costs, and the cost to retrofit a plant must be weighed against the benefits of each WMA technology by the asphalt mix producer in making an investment decision.

Initial results from laboratory testing, accelerated pavement testing, and field trials across the country are very encouraging for WMA. Research is well underway to address such issues as mix design procedures for WMA and to seek ways to eliminate or mitigate any potential damage from the presence of internal moisture in the aggregate or mix. The compactability of WMA offers a unique opportunity to further improve the quality of asphalt pavements by increasing their resistance to fatigue cracking, rut resistance, long-term durability, and resistance to damage from external moisture.

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➜ **UC Berkeley**
Institute of Transportation Studies
1301 South 46th Street
Building 155
Richmond, CA 94804
Phone: 510-665-3410
Fax: 510-665-3454
Email: techtransfer@berkeley.edu

The University of California Pavement Research Center

www.ucprc.ucdavis.edu

➜ **UC Berkeley**
Institute of Transportation Studies
1353 South 46th Street
Building 452, Room 109
Richmond, CA 94804
Phone: 510-665-3411
Fax: 510-665-3562

➜ **UC Davis**
Department of Civil and Environmental Engineering
One Shields Avenue
Davis, CA 95616
Phone: 530-754-8699
Fax: 530-752-9603