Warm Mix Asphalt Technologies and Research

Potential to reduce fuel consumption and emissions.

European countries have been and continue to use technologies that appear to allow a reduction in the temperatures at which asphalt mixes are produced and placed. These technologies have been labeled warm mix asphalt (WMA). The immediate benefit to producing WMA is the reduction in energy consumption required by burning fuels to heat traditional hot mix asphalt (HMA) to temperatures in excess of 300 degrees F at the production plant. These high production temperatures are needed to allow the asphalt binder to become viscous enough to completely coat the aggregate in the HMA, have good workability during laying and compaction, and durability during traffic exposure. With the decreased production temperature comes the additional benefit of reduced emissions from burning fuels, fumes, and odors generated at the plant and the paving site.

There are three technologies that have been developed and used in European countries to produce WMA:

- The addition of a synthetic zeolite called Aspha-Min® (www.aspha-min.com) during mixing at the plant to create a foaming effect in the binder.
- A two-component binder system called WAM-Foam® (Warm Asphalt Mix Foam, www.veidekke.no/english/businessareas/industry/lowtemperatureasphalt), which introduces a soft binder and hard foamed binder at different stages during plant production.
- The use of organic additives such as Sasobit® (www.sasolwax.com), a Fischer-Tropsch paraffin wax and Asphaltan B®, a low molecular weight esterified wax.

The Aspha-Min and Sasobit products have been used in the United States. A fourth technology has been developed and used in the United States to produce WMA:

- Plant production with an asphalt emulsion product called Evotherm™ (www.meadwestvaco.com), which uses a chemical additive technology and a "dispersed asphalt technology" delivery system.

All four technologies appear to allow the production of WMA by reducing the viscosity of the asphalt binder at a given temperature. This reduced viscosity allows the aggregate to be fully coated at a lower temperature than what is traditionally required in HMA production. However, some of these technologies require significant equipment modifications.

This technology could have a significant impact on transportation construction projects in and around non-attainment areas such as large metropolitan areas that have air quality restrictions. The reduction in fuel usage to produce the mix would also have a significant impact on the cost of transportation construction projects.

The benefits of these technologies to the United States in terms of energy savings and air quality improvements are promising, but these technologies need further investigation and research to validate their expected performance and added value. It is important to note that producing HMA at lower temperatures is the desired product to achieve these benefits, not the particular technology that is used to produce the WMA mix.

Product Descriptions

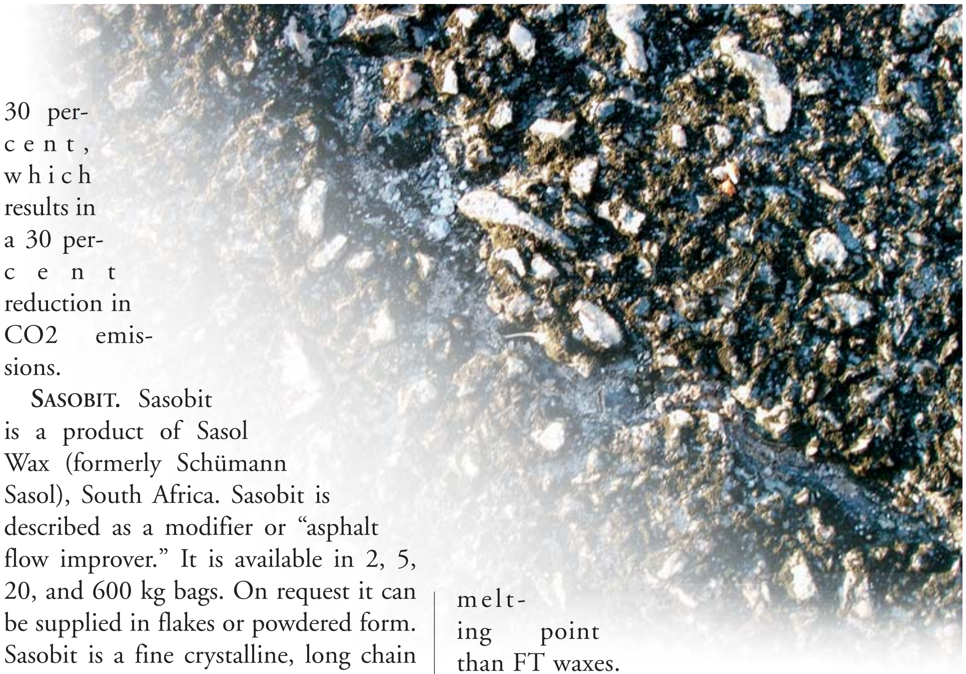
Aspha-Min. Aspha-Min is a product of Eurovia Services GmbH, Bottrop, Germany. It is available in a fine white powdered form in 25 or 50 kg bags or in bulk for silos. It is a manufactured synthetic zeolite (Sodium Aluminum Silicate), which has been hydro thermally crystallized. The percentage of water held internally by the zeolite is 21 percent by mass and is released in the temperature range of 185 degrees to 360 degrees F. By adding Aspha-Min to the mix at the same time as the binder, a fine water spray is created. This release of water creates a volume expansion of the binder that results in asphalt foam and allows increased workability and aggregate coating at lower temperatures.

Eurovia recommends adding Aspha-Min at a rate of 0.3 percent by mass of the mix, which can result in a potential 54 degree F reduction in typical HMA production temperatures. This reduction in temperature is reported to lead to a 30-percent reduction in fuel energy consumption. Eurovia states that all commonly known asphalt and polymer-modified binders can be used as well as the addition of recycled asphalt.

The zeolites are framework silicates with significant vacant spaces in their structures that allow space for large cations such as sodium, potassium, barium, and calcium and even relatively large molecules and cation groups, such as water. In the more useful zeolites, the spaces are interconnected and form long wide channels of varying sizes depending on the mineral. These channels allow the easy movement of the resident ions and molecules into and out of the zeolite structure. The most well known use for zeolites is in water softeners. Zeolites are characterized by their ability to lose and absorb water without damage to their crystal structures. They can have the water in their structures driven off by heat and other solutions pushed through the structure. They can then act as a delivery system for the new fluid.

WAM-Foam. WAM-Foam is a product of a joint venture between Shell International Petroleum Company Ltd., London, and Kolo-Veidekke, Oslo, Norway. In WAM-Foam the binder is formed using two separate binder components in the mixing stage. By dividing the binder into two separate components, a soft binder and a hard binder in foam form, lower asphalt mixture production temperatures can be achieved. The soft binder component is mixed with the aggregate in the first stage at about 230 degrees F to achieve full aggregate coverage. The hard binder component is mixed in a second stage into the pre-coated aggregates in the form of foam. Rapid evaporation of water by injecting cold water into the heated hard binder as it is added to the mix produces a large volume of foam. The hard binder foam combines with the soft binder to achieve the required final composition and properties of the asphalt product.

Shell states that WAM-Foam's success depends on careful selection of the soft and hard components. In some cases it is recommended to use an adhesion improver in the first mixing stage. Shell also states that initial coating of the aggregate in the first mixing stage is vital to prevent water from reaching the binder and aggregate interface and entering the aggregate and that water must be removed from the asphalt mix to ensure a high quality end product. Shell reports that the decreased production temperatures of the WAM-Foam process can lead to plant fuel savings of 30 percent, which results in a 30 percent reduction in CO_2 emissions.



Sasobit. Sasobit is a product of Sasol Wax (formerly Schümann Sasol), South Africa. Sasobit is described as a modifier or "asphalt flow improver." It is available in 2, 5, 20, and 600 kg bags. On request it can be supplied in flakes or powdered form. Sasobit is a fine crystalline, long chain aliphatic hydrocarbon produced from coal gasification using the Fischer-Tropsch (FT) process and is otherwise know as an FT paraffin wax.

In the FT process, carbon monoxide is converted into a mixture of hydrocarbons having molecular chain lengths of 1 to 100 carbon atoms and greater. The starting point for the process is synthesis gas, a mixture of carbon monoxide and hydrogen ($CO + H_2$) produced by gasification of coal, a process involving the treating of white-hot hard coal or coke with a blast of steam. The gas is manufactured in vast quantities for commercial use. It is important in the preparation of hydrogen and as a fuel in the making of steel and in other industrial processes. The synthesis gas is reacted in the presence of an iron or cobalt catalyst; heat is created and products such as methane, synthetic gasoline, waxes, and alcohols are made. The liquid products are separated and the FT waxes are contained.

The makers of Sasobit emphasize the difference between naturally occurring bituminous waxes and FT waxes in terms of their structure and physical properties. The difference reportedly arises from their much longer chain lengths and the fine crystalline structure of the FT waxes. The predominant chain length of the hydrocarbons in Sasobit is in a range of 40 to 115 carbon atoms. The chain lengths of bituminous paraffin waxes naturally found in asphalt range from 22 to 45 carbon atoms, resulting in a lower melting point than FT waxes.

Sasol Wax states that the melting point of Sasobit is approximately 210 degrees F and is completely soluble in asphalt binder at temperatures in excess of 240 degrees F. It produces a reduction in the binder viscosity. This enables production temperatures to be reduced by 18 degrees to 54 degrees F. At temperatures below its melting point, Sasobit forms a lattice structure in the asphalt binder that is the basis for the reported stability of asphalts that contain Sasobit. At service temperatures, Sasobit modified asphalts are reported to display an increased resistance to rutting. In addition Sasol Wax reports improved "compactibility" with an increase in the degree of compaction for the same roller loading as unmodified asphalt.

Sasol Wax recommends adding Sasobit at three percent by weight of the mix to gain the desired reduction in viscosity and should not exceed four percent due to the possible impact on the binder's low temperature properties. Sasobit can be blended into hot binder at the blending plant using a simple stirrer. A high shear mixer is not required. It is anticipated that in-line blending of melted Sasobit with the asphalt binder stream at the plant will be finalized in the near future. Direct blending of solid Sasobit at the plant is not recommended because it will not give a homogeneous distribution of Sasobit in the asphalt.

Evotherm. Evotherm is a product developed by MeadWestvaco Asphalt Innovations, Charleston, S.C. Evotherm uses a chemical additive technology and a “Dispersed Asphalt Technology” delivery system. MeadWestvaco states that by using this technology a unique chemistry customized for aggregate compatibility is delivered into a dispersed asphalt phase (emulsion). During production, the asphalt emulsion with Evotherm chemical package is used in place of the traditional asphalt binder. The emulsion is then mixed with the aggregate in the HMA plant. MeadWestvaco reports that this chemistry provides aggregate coating, workability, adhesion, and improved compaction with no change in materials or job mix formula required.

MeadWestvaco reports that field testing has demonstrated a 100-degree F reduction in production temperatures. MeadWestvaco also reports that the decreased production temperatures of the Evotherm process can lead to plant energy savings of 55 percent; which results in a 45 percent reduction in CO2 and SO2 emissions, a 60 percent reduction in NOX, a 41 percent reduction in total organic material, and benzene soluble fractions below detectable limits.

ASPHALTAN B (NOT USED IN THE UNITED STATES). Asphaltan B is a product of Romonta GmbH, Amsdorf, Germany. It is available in granular form in 25 kg bags. Created specifically for “rolled asphalt,” Asphaltan B is a mixture of substances based on Montan wax constituents and higher molecular weight hydrocarbons.

Crude Montan Wax is found in Germany, Eastern Europe, and areas of the United States in certain types of lignite or brown coal deposits that have formed over millions of years by the transformation of fossilized sub-tropical vegetation that flourished in the Tertiary Period. Wax that once protected the plant leaves from extremes of climate did not decompose, but instead enriched the coal. Due to its high stability and insolubility in water, the wax has survived over long geological time periods. After mining, the Montan Wax is extracted from the coal by means of a toluene solvent that is distilled from the wax solution and removed with super heated steam. Romonta GmbH has a global market share of 80 percent in the crude mined wax products sector.

Romonta recommends adding Asphaltan B at two to four percent by weight. It can be added to the asphalt mixing plant or directly at the binder producer and can also be added to polymer-modified binders. The melting point of Asphaltan B is about 210 degrees F. Similar to FT waxes, it acts as an “asphalt flow improver” with associated reduced production temperatures. Romonta does not specify how much the production temperature can be lowered. Like FT waxes, Romonta also reports increased compactibility and resistance to rutting.

Initial Research

The National Asphalt Pavement Association (NAPA, www.hotmix.org) in cooperation with the Federal Highway Administration (FHWA) proposed a research program to investigate the performance of WMA products. Initial research was conducted on the feasibility of using these technologies in the United States through a cooperative agreement between the National Center for Asphalt Technology (NCAT, www.ncat.us) and FHWA. This study also included additional monetary support from NAPA and the individual technology providers. This initial research has been completed and the findings have been published by NCAT. The reports can be found on their website published as:

- *Evaluation of Evotherm for Use in Warm Mix Asphalt (Report 06-02)*, by Graham C. Hurley

Research Engineer, National Center for Asphalt Technology, Auburn University, Auburn, AL, and Brian D. Prowell, Assistant Director, National Center for Asphalt Technology, Auburn University. The report concluded: “Evotherm was shown to improve the compactibility of mixtures in both the Superpave Gyratory Compactor (SGC) and vibratory compactor. Statistics indicated an overall reduction in air voids. Improved compaction was noted at temperatures as low as 190 degrees F. The addition of Evotherm does not statistically affect the resilient modulus of an asphalt mix nor does it increase the rutting potential of an asphalt mix as measured by the Asphalt Pavement Analyzer. The rutting potential did increase with decreasing mixing and compaction temperatures, which may be related to the decreased aging of the binder resulting from the lower mixing and compaction temperatures. There was no evidence of a difference in indirect tensile strength gain with time for the mixes containing Evotherm as compared to the control mixes, indicating that a WMA containing Evotherm can be quickly opened to traffic. The lower compaction temperature used when producing WMA with Evotherm or any WMA additive may increase the potential for moisture damage. Overall, Evotherm appears to be a viable tool for reducing mixing and compaction temperatures that can be readily added to hot mix asphalt. Reductions in mixing and compaction temperatures are expected to reduce fuel costs, reduce emissions, and widen the winter paving window.”

- *Evaluation of Sasobit for Use in Warm Mix Asphalt (Report 05-06)*, by Hurley and Prowell, which concluded: “Sasobit was shown to improve the compactibility of mixtures in both the SGC and vibratory compactor. Statistics indicated an overall reduction in air voids. Improved compaction was noted at temperatures as low as 190 degrees F. The addition of Sasobit does not affect the resilient modulus of an asphalt mix nor does it increase the rutting potential of an asphalt mix as measured by the Asphalt Pavement Analyzer. The rutting potential did increase with decreasing mixing and compaction temperatures, which may be related to the decreased aging of the binder resulting from the lower temperatures as well as from the anti-aging properties of Sasobit. There was no evidence of differing strength gain with time for the mixes containing Sasobit as compared to the control mixes indicating that a prolonged cure time before opening to traffic is not an issue. The lower compaction temperature used when producing warm asphalt with Sasobit or any such similar Warm

Mix additive may increase the potential for moisture damage. Overall, Sasobit appears to be a viable tool for reducing mixing and compaction temperatures that can be readily added to hot mix asphalt. Reductions in mixing and compaction temperatures are expected to reduce fuel costs, reduce emissions, widen the winter paving window, and facilitate specialized applications, such as airport runway construction, where rapid opening to traffic is essential."

- *Evaluation of Aspha-Min Zeolite for Use in Warm Mix Asphalt (Report 05-04)*, by Hurley and Prowell, which concluded: "A laboratory study was conducted to determine the applicability of Aspha-Min to typical paving operations and environmental conditions commonly found in the United States, including the performance of the mixes in quick traffic turn-over situations and high temperature conditions. Aspha-Min was shown to improve the compactibility of mixtures in both the SGC and vibratory compactor. Statistics indicated an average reduction in air voids of 0.65 percent. Improved compaction was noted at temperatures as low as 190 degrees F. The addition of zeolite does not affect the resilient modulus of an asphalt mix. The addition of zeolite does not increase the rutting potential of an asphalt mix as measured by the Asphalt Pavement Analyzer. The rutting potential did increase with decreasing mixing and compaction temperatures, which may be related to the decreased aging of the binder. There was no evidence of differing strength gain with time for the mixes containing zeolite as compared to the control mixes. There is no indication that HMA containing Aspha-Min requires a cure period prior to opening to traffic. The lower compaction temperature used when producing warm asphalt with Aspha-Min may increase the potential for moisture damage as indicated by tensile strength ratio (TSR) and Hamburg tests. However, the addition of hydrated lime mitigated this effect.

  "A demonstration project was constructed using Aspha-Min zeolite in Orlando, FL. The warm mix production and compaction temperatures were 35 degrees F less than those used for the control (about 300 degrees F compaction temperature). The laboratory test results on the field mix coincide with the laboratory study. Cores taken one year after placement indicated no increased evidence of moisture damage as compared to the control mix. Overall, Aspha-Min zeolite appears to be a viable tool for reducing mixing and compaction temperatures that can be readily added to hot mix asphalt. Reductions in mixing and compaction temperatures are expected to reduce fuel costs and emissions and also widen the winter paving window."

The National Cooperative Highway Research Program has approved research Project 09-43 "Mix Design Practices for Warm Mix Asphalt Technologies" for fiscal year 2007, with completion scheduled for 2010. The objective of this research project is to develop a performance based mix design procedure for warm mix asphalt in the form of a manual of practice. Additional information can be found at www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+9-43.

The FHWA Office of Pavement Technology is actively involved with all these research projects and demonstrations and is also working in cooperation with FHWA Turner-Fairbank Highway Research Center's (TFHRC) Bituminous Mixtures Laboratory to develop and monitor WMA demonstration projects and research and also to advance the knowledge and state of practice of these materials and technologies. FHWA will actively support further WMA research and validation through material sampling and performance testing provided through the Office of Pavement Technology's Mobile Asphalt Mixture Testing Laboratory (MAMTL) in addition to continued WMA research activities at TFHRC.

The MAMTL was on site for material sampling and testing during the Missouri Department of Transportation WMA demonstration project on Hall Street in St. Louis. This demonstration project included construction of asphalt pavements using the Aspha-Min, Sasobit, and Evotherm products by Pace Construction. A large amount of volumetric and performance specimens were immediately fabricated for testing in addition to loose mix sampled for later testing to investigate any effects due to reheating and residual moisture. The immediately fabricated specimen testing has been completed. A final report of the test results and findings will be published upon completion of all testing and analysis.

The Transportation Research Board (www.trb.org) is conducting a detailed evaluation study to assess the performance of WMA mixes and pavements both in field test sections and in the controlled environment of an accelerated test facility. Sponsored by the Federal Highway Administration, the performing organization is the University of Ohio, Athens, OH. Primary objectives of the research are:

- To conduct a detailed laboratory study to evaluate the engineering and physical properties of WMA mixtures.
- To build and test pavement sections containing selected mixtures as a wearing course.
- To examine the influence of pavement thickness on the tensile strain developed at the bottom of the perpetual pavement layer.
- To monitor and test pavement sections.
- To compare the performance of WMA mixtures and pavements with that of conventional HMA.
- To document the performance of perpetual pavements containing WMA
- To assess the advantages of WMA over conventional HMA in regard to reduced energy utilization and fume emanation during processing and placement.

This project is expected to be completed in August 2008. GE