Summary of Asphalt Additive Performance at Selected Sites

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In 1990, a survey of modified asphalt test pavements was conducted to examine performance during construction and service while using the various additives on the market. Representatives from 14 states, Austria, and Canada were contacted to survey the field performance of more than 30 end-to-end test pavements where one to five asphalt additives, modifiers, or modification processes have been evaluated. States contacted include Alabama, California, Colorado, Indiana, Louisiana, Maine, Minnesota, Montana, New Jersey, Texas, Utah, Vermont, and Virginia. Additives include styrene butadiene rubber (SBR) latex, Styrelf-13 (SBR reacted with asphalt), DuPont neoprene latex, styrene butadiene styrene block copolymer (Shell Kraton), polyethylene (Novophalt process), ethylene vinyl acetate (Exxon and DuPont), Solar Laglugel (nylon resin polymer), Gilsonite, asphalt-rubber (tire rubber), Dow polymers (unknown), Plus-Ride (ground tire rubber replacing aggregate), Microfil-8 (pelletized carbon black with oil), Celite (diatomaceous earth), Chemkrete, hydrated lime, fly ash, Acra 500, and fibers. Most of the results have been collected by telephone and are, therefore, qualitative. Some of those contacted have sent written reports that provide more quantitative data. Unfortunately, many of the test pavements are less than 5 years old and show no differences in performance.

The objective of this work was to rapidly summarize information on construction and relative field performance of modified asphalt test pavements in North America and Europe. In 1 week, representatives of at least 14 states, Canada, and Austria were contacted. Information was collected on more than 30 test sites where adjacent test pavements were built to evaluate one to five asphalt modifiers. Field performance of about 20 different modifiers was examined.

Most of the findings were obtained by telephone and, therefore, are qualitative and subjective in nature. Some more quantitative findings from written documents are also presented.

FIELD PERFORMANCE

Findings from this survey are summarized in Tables 1 and 2. Table 1 gives a brief description of the test pavements, field operations, and performance. Table 2 contains a brief synopsis of the perception of the individual user agency representative regarding asphalt additive performance and a prognosis of future use by the agency.

ADDITIVES AVAILABLE

Most of the known asphalt additives available in today's market (*12*) have been categorized by generic name in Figure 1.

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Some of these products are used routinely in bituminous paving mixtures; others are still in the experimental stage.

Polymers including neat rubbers are the most versatile and probably hold more promise to improve structural and adhesive properties of bituminous pavements than any other single category of additives on the market today. Generally, the polymer-type additives are shown to reduce binder temperature susceptibility and brittleness and increase toughness (energy of deformation) and tenacity. Polymers in asphalt mixtures have exhibited moderate improvements in Marshall stability and tensile properties but generally no significant increase in Hveem stability. (Although Hveem stability is sensitive to binder content, it is not sensitive to binder properties.) Specialized laboratory tests designed to estimate resistance to pavement cracking and permanent deformation often show significant benefits when polymers are used.

Latexes have been used experimentally in bituminous paving applications for more than 30 years and now enjoy widespread use. The term "latex" is derived from the natural rubber industry and describes the milky fluid that comes from rubber trees (or even dandelions). The term has been adopted to describe the initial product, which is synthetic rubber emulsified in water, from the rubber manufacturing process. Different types of synthetic rubber are available in the latex form. The latex most widely used in the paving industry is styrene butadiene rubber (SBR). SBR latex is routinely used in chip seals in many parts of the country. It is becoming more frequently used in hot paving mixtures. Several asphalt producers and suppliers have recently made plant modifications to facilitate the supply of SBR latex modified asphalt and thus save the user the trouble of blending the two products. The primary reason for the widespread use of SBR latex is its availability and relative cost compared with competing polymers. Neoprene latex has also been used for many years in bituminous pavements but with much less frequency than SBR latex.

Pelletized carbon black containing about 8 percent oil as a binder for the pellets has also demonstrated positive results in improving asphalt pavement performance (*13*). Carbon black has been incorporated into bituminous paving mixtures by adding preweighed plastic bags of the material into the pug mill at a weigh batch hot mix plant. Heretofore, carbon black dispersed in hot asphalt cement quickly settled out when stored statically because of the difference in specific gravity of the two materials. Dispersing agents have been developed that will keep the carbon black in suspension and thus permit its use in drum mix plants (*14*). The dispersion process requires specialized equipment and adds significantly to the cost of the modified asphalt. More recently, a portable blending unit has

TABLE 1 SUMMARY OF ASPHALT ADDITIVE PERFORMANCE IN HOT MIXED ASPHALT CONCRETE

Location	Additives Tested	Date Placed	Pavement Section	Climate	Traffic	Summary of Findings/ Performance in 1990
Alabama (highway not specified)	Styrelf, Elvax, Novophalt, Gilsonite and Neoprene	1987	(Not Specified).	Moderate	Not specified	Gilsonite was troublesome to handle since it was supplied in 50-100 pound bags. It was mixed in the storage tank. Modified asphalts caused no problems during mixing, placement, or compaction. There are no significant difference in performance.
California IH-80 near Alta (elevation 3,000 ft.)	Kraton with Dutrex extender oil (furnished as an AR-4000 preblended at the refinery), Bonifibers (polyester fibers), Fiber Pave (poly propylene fibers), Carbon black, Ramflex (devulcanized rubber)	June 1985	1.8" surface course 1.2" leveling course cracked and seated PCC pavement.	Severe Winters	Not specified	Test sections ranged from 1,000 to 2,000 feet in length. Placement temperatures were above 325°F. Rocks were occasionally picked up by the roller on the polymer-modified. As a result of a few unusually mild winters, all pavements are performing well; there are no differences in pavement performance associated with the additives (1).
California (highways not specified)	Asphalt-rubber (A-R) and Plus-Ride	1987	(Not specified). Thickness of some of the A-R sections was reduced to compare to control sections.	Cold	Not specified	Reflection cracking was more severe in the control sections and in the thinner A-R sections than in the A-R sections that were the same thickness as the control sections. In test sections installed at Ravendale in 1987, the A-R sections have "far outperformed" the control pavements and are exhibiting less cracking. Plus-Ride is performing equivalent to A-R.
California IH-10 East of Indio	Styrelf PAC-40 produced by Elf Aquitaine Asphalt (manufactured using Edgington AR4000 asphalt), a polymer modified AR-4000 produced by Witco (Golden Bear), and Novophalt (a blend of Paramount AR-4000 asphalt and polyethylene pellets mixed at the plant site using a special Novophalt unit).	September 1988	4.2" of previous overlay was cold planed and replaced with 4.2" of an all crushed 1 1/4" maximum size coarse graded AC base mix (using AR-8000), 3" of 3/4" maximum size coarse graded surface mix (also AR-8000). Modifiers were used in the coarse graded surface mix in the number 2 lane.	Desert	Not specified	Test sections were 0.25 miles in length. No unusual problems were encountered during mixing and placing. After two years, some rutting (1/4" - 3/8") has appeared in isolated areas in the Golden Bear section, likely due to high binder contents. Tests indicated lower in-place voids (3.3 percent) compared to other sections (4.3 - 5.4 percent) (2).
California US 395 adjacent to the Caltrans Crestview Maintenance Station about 50 miles of Bishop (elevation 800 feet)	Polymer modified binders were supplied by Conoco and Witco (Golden Bear - AR 4000) and were preblended prior to arrival at the plant site. The suppliers of the modified asphalts were to use as a guideline the Caltrans proposed durable asphalt specification plus a minimum penetration at 39.2°F of 35 dmm on the residue from thee RTFO procedure.	1988	4.8" overlay with 3/4" maximum size aggregate.	Cold	Not specified	After two years, the unmodified pavement is showing about three cracks per 100 feet in the surface while the modified pavement (Golden Bear) has none. Results from the Conoco section are not known.
Colorado (highway not specified)	AC-20R: a SBR-treated AC-10 asphalt meeting AC-20 specification after modification.	Not specified	Not specified	Cold	Not specified	After three years in service, the AC-10 section is exhibiting about twice as much cracking as the modified section.
Indiana Hwy 465, and US 41 (city of Terre Haute)	SBR latex, Novophalt, neoprene, Styrelf, asphalt-rubber, polyester fibers, polypropylene fibers.	1988	All three layers contain additives and the surface layer was overlaid over cracked and seated concrete pavement.	Cold	Not specified	There are no differences in performance of the various sections on Hwy 465. For US 41, the polymer test section is in excellent shape in spite of a low air voids. The control sections are showing significant rutting.
Louisiana Hwy 46 from Haydras to Riggio	Styrelf and SBR latex	1984	3/4" thick open graded friction course (OGFC) containing AC-30 at 6.1 or 6.7 percent binder, styrelf at 6.1 or 6.7 percent binder or latex at 6.7 percent binder.	Warm	Not specified	After 2 to 3 months in service, raveling in the control sections was detected at turnouts. After 5 years in service, the polymer modified sections began to ravel. After 6 years, the control sections are in very poor condition while the modified sections are in excellent condition. The key factor to the differences in performance is the binder film thickness, which was insufficient at 6.1 percent. The polymers have shown little positive benefit.

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TABLE 1 *(continued)*

Location	Additives Tested	Date Placed	Pavement Section	Climate	Traffic	Summary of Findings/ Performance in 1990
Louisiana La 686	The control asphalt was Texaco AC-30. Three percent SBR latex was blended in a drum plant with AC-10, and Styrelf was preblended with AC-10.	1986	2" overlay over 3" badly cracked overlay surface treatment cement treated base.	Warm	Not specified	Within one week after construction, all sections began to crack. After four years in service, all overlays are performing similarly. The styrelf section is performing a little better than the latex, and the latex section is performing better than the control section. Extractions after one year revealed the latex binder was aging faster than the Styrelf binder.
Louisiana Florida Boulevard in Baton Rouge	Latex (metered directly into pug mill)	Fall 1987	2" overlay with 3/4" maximum size siliceous river gravel and sand (8 percent minus No. 200).	Warm	81,000 ADT	The control asphalt was an AC-30 and the modified asphalt was an AC-10. After two years, rutting in the control sections measured 0.5 inches and rutting in the latex section measured less than 0.2 inches. No flushing has occurred in either section (3).
Louisiana US 190	Ultrapave 70 latex	1988	Overlay on existing PCC pavement.	Warm	Not specified	The latex-modified asphalt concrete is controlling reflective cracking better than the control mix (4).
Maine IH-95	Ultrapave latex, Dow polymers (identified by number) and latexes	1981 and September 1986	2" overlay	Cold	Not specified	1981 tests of Ultrapave latex are showing no significant differences in performance of the control sections and the latex sections. Test sections for the Dow polymers and latex were 1,000 feet in length. The test sections were made with asphalts modified with No. 1 polymer, No. 2 polymer, latex and blends of each polymer with latex. Some sections have performed poorly and some have performed well.
Minnesota City of Rosenville	Polysar latex +200-300 pen asphalt (sprayed into drum mix plant) The control asphalt was 120-150 penetration grade.	1986	1" - 2.5" HMAC surface composed of 40 percent crushed stone and 60 percent gravel and sand with a maximum aggregate size of 0.5 inch.	Cold	Not specified	In all construction projects with the rubber additives, the DOT noted the presence of rubber-rich globules in the mix. These globules appeared on the finished pavement surface as binder-rich spots about the size of a silver dollar. The department is evaluating cracking, rutting, and flushing in these pavements. Currently, all pavements are performing well and there are no observable differences between the test pavements.
Minnesota Hwy 61 South of Hastings and just north of intersection with Hwys 50 and 20.	Dupont neoprene latex L735A (introduced directly into drum mix plant)	May and June of 1988	1. Neoprene modified RAP mix in the binder course with unmodified virgin mix in the wearing course; 2. Modified RAP in the binder course with modified virgin mix in the wearing course; 3. Unmodified binder course with modified wearing course; and 4. Unmodified binder and wearing courses (control).	Cold	Not specified	During paving operations, the mixture showed evidence of unmixed neoprene in the form of small globs which later appeared as binder-rich spots on the paved surface. No performance results are available.
Minnesota Trunk Highway 63	Carbon black (Cabot Microfil) and sulphur to reduce reflective cracking.	1984	1.5" overlay 3" bituminous surfacing 6" crushed rock base 12" sand and gravel subbase.	Cold	1,600 ADT	The two additives were blended with a 200-300 penetration asphalt. One section contained an untreated 200-300 penetration asphalt and the control section contained a 120-150 penetration asphalt. Soon after construction, the 200-300 penetration asphalt section began flushing badly while the treated sections did not. None of the materials were successful in preventing reflective cracking. The carbon black section has the least cracking. Laboratory tests of extracted binders indicate that carbon black is retarding oxidative hardening. Rutting is minor, but the section with the 200-300 penetration asphalt is exhibiting more rutting (5).

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TABLE 1 (*continued*)

Location	Additives Tested	Date Placed	Pavement Section	Climate	Traffic	Summary of Findings/ Performance in 1990
Montana IH 90 near Big Timber	Hydrated lime, Acra 500 (antistrip fly ash, Chemkrete and Microfil 8 (carbon black)	1983	4.8" bituminous surface course placed in two lifts.	Cold	Not specified	Two asphalts were used, a 120-150 penetration grade and a 200-300 penetration grade. The aggregate was a 3/4" maximum size crushed stone with 6 percent minus No. 200 materials. The carbon black was added at the drum plant. A significant amount was removed by the exhaust gas cleaning system and ended up floating on the surface of the sump pond. It tended to plug the feed lines from the silo to the plant. While placing the first lift, the Chemkrete mix appeared tender at times. During the first summer, the Chemkrete section began to flush and rut (1/4 inch). After two summers, the sections containing Chemkrete, ACRA-500 and the 200-300 asphalt had ruts greater than 1/4 inch while the other sections had ruts less than 1/4 inch. Minor cracking had appeared in all test sections. Rut depths increased after the hottest summer in 50 years (1988) (6).
New Jersey Route 41	Chemkrete, Texcrete (SBR latex), solar Laglugel, 3M #5990 (Polyethylene pellets) and Plus Ride.	August 1984	1.5" HMAC surface course.	Cold	11,200 ADT	Test sections are approximately 36 feet in width and 1740 feet in length. Generally, most of the pavement sections are performing well with no major differences between the different sections. The 3M #5990 was the least resistant to cracking. The cold joints cracked soon after construction and the sections now has 84 feet of transverse cracks. The Texcrete section has a small amount of fatigue cracking in the wheelpath and about 10 feet of transverse cracking. The other sections have only 10 feet of transverse cracks. None of the test sections are exhibiting significant rutting (1/8" - 1/4" ruts).
New Jersey Route 35	Exxon EVA, Novophalt, Gilsonite, Carbon Black, Kraton, Solar Lag	November 1987	3" HMAC overlay placed in two lifts.	Cold	30,000 ADT	The only significant difference between test sections is rut depths, with the control AC-20 exhibiting the lowest rut depths. Raveling, usually a moisture related problem, is not uncommon in carbon black modified asphalt pavements. Cracking developing is most likely related to the weak substrate on which these overlays were placed.
Texas SH 121 in Fort Worth	SBR latex (Polysar, Ultrapave, and DOW) - added in the drum plant	Summer 1985	2" overlay with 3/8" maximum size lightweight synthetic aggregate and field sand) on a geotextile placed on CRCP.	Warm	12,000 ADT	Within one year after construction, rutting and flushing was significantly greater in the control section (with 8.5 percent asphalt content) than in the latex section (with 7.5 percent asphalt content). The control section had to be removed and replaced. The latex sections are still performing well after five years.
Texas US 83/77 in South Texas near Brownsville	Microfil - 8 (preblended), Polybilt-102, Ultrapave - 78 latex, and Kraton D with Dutrex extender oil	August 1986	3" HMAC modified test sections and 4" HMAC control test sections with 3/8" maximum size crushed river gravel and field sand. All mixes contained one percent hydrated lime as a slurry.	Tropical	15,000 ADT	Two 1/4-mile test pavements containing each additive were placed as new construction in the outside lane of a 4-lane divided highway. The modified test sections used an AC-10 asphalt while the control section used an AC-20 asphalt. During construction, the latex caused the mix to cling to the beds of the haul units and caused notable drag on the paving machine. After 3.5 years in service, there are no significant differences in the appearance of the test pavements that are attributable to the additives. Rutting in all the sections ranges from 0 to 1/8 inch.

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been developed and will soon be available for use at mixing plants to alleviate the problems of blending Microfil in the field.

Asphalt rubber in paving mixtures as well as stress-absorbing membrane interlayers (SAMI) has been tested extensively in highway pavements (*15–19*). This product, composed of ground tire rubber in asphalt, typicaly requires 18 to 22 percent rubber by mass of asphalt cement. The rubber must be ground to a minus number 10 sieve size, which requires significant effort and cost. The material decreases the ductility of asphalt to such an extent that it will not meet many state department of transportation specifications. It will probably not be cost-effective compared with products that contain 2 to 5 percent neat polymer. Pressure from the federal government, how-

TABLE 1 (*continued*)

Location	Additives Tested	Date Placed	Pavement Section	Climate	Traffic	Summary of Findings/ Performance in 1990
Texas US 75 near Sherman	Elvax-150, Novophalt, Kraton D with Dutrex extender oil, Ultrapave 70 latex, and Microfil - 8 (added in plastic bags at the pugmill). All polymers except Novophalt were preblended prior to arrival at the construction site.		3" HMAC modified test sections and 3" and 4" HMAC control sections with 5/8" maximum size crushed limestone and field sand.	Warm-Moderate	18,000 ADT with 17 percent trucks	The test pavements were 1/2-mile in length in the outside lane of a 4-lane divided facility composed of an old, cracked CRCP. All additives were blended with AC-10 and the control sections contained AC-20. After 3.5 years in service, there are no detectable differences in the visual appearance of the sections. The pavements are performing well and the ride quality is approximately equivalent.
Texas US 59/71 near Texarkana	Ultrapave latex, Chemkrete (CTI-102), Polybilt 102, and Styrelf-13	Fall 1987 through Spring 1988	2" surface mix with 3/8" maximum size crushed sandstone with field sand. 8" asphalt stabilized based with 7/8" maximum size crushed sandstone with field sand.	Moderate	10,000 ADT with 15 percent trucks	The test sections were 0.9 mile in length and comprise both lanes of a 4-lane divided facility. The control pavement contains AC-20. Latex was blended with AC-10, styrelf was preblended with soft asphalt, and the Chemkrete and Polybilt were blended with AC-20 at the plant site. During construction, the latex and styrelf mixtures tended to stick to the tires of the pneumatic roller. After two years in service all pavements are performing well and the surfaces of the pavements have equivalent appearance.
Vermont Montpelier State Hwy.	Solar Laglugel - a resin and nylon base modifier supplied by Additives of New England, Inc.	October 1982	1 1/4" overlay.	Cold	Not specified	The modified mix gave off a strong odor and was stickier than the standard mix but presented no significant problems during placement. The DOT monitored reflective cracking, rutting, bituminous mix properties, ride quality, surface friction values and maintenance requirements in these pavements for five years and saw no cost effective or beneficial effects. In general, there was little difference in performance between the modified and unmodified pavements (7).
Vermont Route 12 near the Worcester/Elmore town line between milemarker 0670 and milemarker 0701	Ultrapave latex (SBR)	September 1984	1" surface course.	Cold	Not specified	There were no significant problems with the production or placement of the HMAC. Several "fat spots" stuck to the compaction roller and pulled out leaving small "pock marks" in the pavement surface. Workers commented that the material was very sticky and stringy, making hand work more difficult. Crack counts and rutting surveys have indicated no detectable differences in the performance of the latex modified test sections and the control test sections.
Virginia Route 58	Polybilt - 100, Dow Downright HM 100L, Styrelf-13, Ultrapave and a Celite 292 sedimentary diatomaceous deposit filler. The evaluation of these additives to improve the deformation and flexibility characteristics of asphalt paving mixtures was investigated.	1986	1.5" overlay over milled asphalt pavement.	Cold	Not specified	The test sections ranged in length from 0.6 to 0.8 miles. There are no discernable differences between the sections containing the various additives. Considerable stripping was evident in the pavement cores containing the Celite; this stripping is expected to affect performance eventually. The additives were not considered cost effective on this project because traffic was not severe enough to cause significant rutting in the conventional control mix (9), (10).
Virginia	Polybilt, Microfil-8 and fibers	1989	Not specified	Cold	Not specified	Test sections made from Polybilt modified asphalt concrete are performing well. Microfil-8 was used in a bridge deck; it appears to have improved resistance to plastic deformation in a fine-grained, low void mix. Fibers have been used in small installations; no valid conclusions can be made at this time.
Austria Vienna Metropolitan Hwy at Praterhochbruecke	Novophalt	1980	Not specified	Cold	Not specified	After 8 years in service, the Novophalt section was exhibiting 0.16 to 0.24 inches of rutting; the control section was exhibiting 0.70 to 1.0 inches of rutting.

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TABLE 1 (*continued*)

Location	Additives Tested	Date Placed	Pavement Section	Climate	Traffic	Summary of Findings/ Performance in 1990
Austria Semmering Freeway - S6 at Wartmannstetten and Oberdanegg	Novophalt - in the surface course only	1983	2.0" surface course 2.4" binder course Section I - untreated control pavement using limestone aggregate. Section II - similar to section I but with Novophalt in the surface course. Section III - Similar to Section II but basalt aggregate was used in the surface course.	Cold	Not specified	After four years in service, Section I had 0.16 inches of rutting, Section II had 0.11 inches of rutting, and Section III had 0.22 inches. These rut depths are not considered serious; 0.5-inch ruts are usually considered the minimum for which maintenance is required.
Canada City of Edmonton Highway not specified	A polymer supplied by Imperial Oil (Exxon) and SBS rubber from Husky Oil.	1987	2" surface course	Cold	High volume, heavy truck traffic	After two years, more cracking was evident in the Imperial Polymer section than in the control section. There was no appreciable rutting in either section. A SBS rubber product from Husky Oil was used in a 2" overlay on an old portland cement concrete pavement. Spacing between cracks in the old pavement was about 50 feet. Cracks reflected through in about two months. In three years of service, no rutting occurred. Asphalts modified with the Husky product are reportedly very stable during prolonged hot storage, giving no evidence of phase separation or loss of viscosity.
Canada City of Edmonton Highway not specified	Novophalt	1987	8" surface layer.	Cold	High volume, heavy truck traffic	After three years, the Novophalt modified pavement is exhibiting significantly less rutting than the control pavement (0.25-inch versus 0.5-inch). There is no significant cracking in these pavements.
Canada City of Montreal Autoroute 20	Styrelf	1987	Open-Graded Hot Mix	Cold	Heavy	After 3 years pavement is performing better than materials used previously to pave this troublesome section of roadway. Styrelf controled draindown during handling of the open-graded mix (11).

ever, may promote its use in some instances when it is not cost-effective to minimize the solid waste disposal problem with automobile tires.

As mentioned previously, most of the polymer, rubber, and carbon black additives improve the temperature susceptibility of an asphalt. This change in the rheological properties of the asphalt depends, of course, on the type of additive and the quantity added. Generally, one can expect a significant increase in binder viscosity at temperatures above 40°F and no appreciable change in consistency at temperatures below 40°F. Therefore, by using an asphalt one or two grades softer than that normally used in hot mix asphalt concrete plus an appropriate additive, one can take advantage of the original low viscosity of the asphalt in the low temperature range to increase resistance to cracking and, simultaneously, depend on the higher viscosity in the high temperature range to increase resistance to rutting on highways and depressions made by tires in parking areas.

OTHER CONSIDERATIONS IN THE USE OF ADDITIVES (*12*)

The primary disadvantage of the increased viscosity of the modified binders at high temperatures is that it extends into the temperature range at which asphalt concrete is mixed (275°F to 325°F). It is, therefore, often necessary to increase the operating temperature of the mixing plant to achieve adequate coating of aggregate and provide for satisfactory compaction of the paving mixture. Plant temperature increases from 0°F to 70°F have been reported, with about 30°F being most usual. Obviously, the required temperature increase will depend on the type and quantity of additive used. This is, nevertheless, an important consideration for the paving contractor from an economic standpoint, in that more fuel will be required to operate the plant at a temperature higher than normal. Higher mixing temperatures can result in improved resistance of the mix to damage by moisture (*20*), which, in times past, may have been attributed to the additive.

When a given quantity and type of polymer is added to an asphalt product, the resulting physical properties of the binder will vary with asphalt source. Crude petroleums from various parts of the world vary significantly in chemical composition. Refining processes also cause variation in the chemical makeup of asphalt cement. The aromatic polymers, like SBR latex, may be more compatible with the more aromatic asphalts. Asphalts high in asphaltenes (above 25 to 30 percent) are generally not well peptized and, therefore, may exhibit poor compatibility with most polymers.

Many paving agencies specify an extraction procedure to verify the presence of the design quantity of bituminous binder. Some of the polymers and carbon black are only partially soluble or insoluble in the conventional solvents and, as a result, interfere with the extraction process and may cause

TABLE 2 COMMENTS FROM REPRESENTATIVES OF STATE DEPARTMENTS OF TRANSPORTATION ABOUT USE OF ASPHALT ADDITIVES IN HMAC, 1990

Location	Perception of the User About Additives	Plans for Future Use
Alabama	Additives appear to have promise.	The DOT will not buy polymer additives for HMAC in the near future, but will in the distant future.
California	DOT likes to use polymer additives because they can use softer asphalts which age at a slower rate in the desert climates and crack less in the cold climates.	The DOT will regularly use modified asphalt.
Colorado	The DOT believes the rubber-type polymers are cost effective in reducing rutting, cracking, and stupping.	The DOT uses significant amounts of rubber-type polymers in their routine asphalt pairing operations and will likely increase the use of these additives.
Iowa	DOT believes that most polymers appear to make significant changes in asphalt material properties but are not cost effective regarding pavement performance.	DOT will probably not buy polymer additives for general use.
Indiana	The DOT believes fibers are cost effective in reducing reflection cracking over cracked and seated concrete pavement. Fibers reduce the thickness of the overlay.	The DOT will continue to use fibers and is developing thickness equivalency factors.
Louisiana	Latex modified mixes are showing increased benefits over the conventional mixes in controlling reflective cracking. The DOT believes polymers and latex are cost-effective in some applications. The ability of the polymers to enhance binder properties at both high and low temperatures should provide for longer service life in dense and open-graded mixtures.	The DOT will specify polymers and latex to address special problems or situations where it is anticipated that cracking or rutting would occur in conventional mixes.
Maine	DOT believes additives improve pavement performance but not to an extent that they are cost effective.	DOT does not anticipate using large quantities of polymer-type asphalt additives in the near future.
Minnesota	The DOT considers additives, such as carbon black and sulphur, to be experimental.	The DOT will continue to test new additives as they appear on the market. It will likely be several years before they purchase large quantities of additives for routine use.
Montana	The DOT has a genuine interest in the cost effectiveness of various asphalt additives.	The DOT will continue to monitor performance of test pavements in an attempt to develop correlations between pavement performance and various binder properties.
New Jersey	The DOT considers additives and other modifications to be experimental.	They do not plan to use additives routinely in the near future.
Texas	DOT is observing several experimental pavements, uses additives occasionally to address special problems.	Will continue to monitor performance and specify additives in special situations.
Utah	Utah uses latex and hydrated lime routinely in their hot mix work. They have been using latex since the 1960's. Latex is used in areas of high volume or stop and go traffic, places where early pavement distress is expected. Lime is required for marginal mixes to meet specifications for the AASHTO T283 moisture treatment procedure	They will continue to specify latex.
Vermont	The DOT believes additives offer improvements in asphalt pavement performance but that they are not usually cost effective.	The DOT does not anticipate the routine use of asphalt additives in the near future.
Virginia	Additives are too expensive to use routinely on long stretches of interstate highways.	The DOT will probably use additives for special situations where early distress may be expected due to high volume, heavy traffic or intersections.

erroneous results. Some agencies go a step further and periodically recover the bituminous binder from the extraction solvent to determine its physical properties. Properties of polymer-modified binders recovered after the extraction process are questionable because, even if all the modified binder is recovered, the additive and bitumen have been intimately and unrealistically blended in the procedure, which, in all probability, significantly changed the rheological properties.

Tests to verify the quantity of polymer in bitumen are not difficult but are time-consuming and expensive. Fourier transform infrared (FTIR) analysis, with careful calibration, using mixtures of known quantities of bitumen and polymer, can readily be used to determine the polymer content of a modified binder (*21,22*). However, for reasons discussed previously, the difficulty factor rises sharply if the modified binder must be first extracted from an aggregate mixture.

Heat stability of polymer-modified binders has been evaluated in an attempt to predict problems that might occur during prolonged hot storage (*23*). After exposure to 325°F for 24 hr while protected from oxidation, SBR and SBS products exhibited a significant decrease in viscosity. The drop in viscosity is apparently due to a breakdown of the molecular structure of the polymer. Similar findings have been reported from the field after prolonged hot storage in a tank. In one case, the user agency rejected the modified binder because it no longer met viscosity specifications. In another case, the damaged binder was used, but significant mixture tenderness was noted during construction. One highway district in the Texas Department of Transportation specifies that SBR latex be added to the asphalt mixture in the mixing plant to avoid hot storage and possible damage to the modified asphalt.

BENEFIT-COSTS FOR ADDITIVES

Costs of the most widely used polymer additives are influenced by the cost of crude oil, as is the cost of asphalt cement. Currently, the price for the commonly used polymers ranges from \$0.80/lb to \$1.00/lb. For the carbon black, the price is about \$0.50/lb. This translates into a cost increase of about \$4.00/ton to \$9.00/ton of hot mixed asphalt concrete, depending on the dosage of the additive. On the basis of an in-

1. Polymers
    a. Styrene Butadiene Rubber (SBR) (Latex)
    b. Block Copolymers
        i. Triblock Styrene-Butadiene-Styrene (SBS)
        ii. Radial Block SBS
        iii. Vulcanized (SBR)
        iv. Styrene-Isoprene-Styrene (SIS)
        v. Styrene-Ethylene-Butylene-Styrene (SEBS)
        vi. Styrene-Ethylene-Propylene-Styrene (SEPS)
    c. Polyethylene
    d. Ethylene Vinyl Acetate (EVA)
    e. Polypropylene
    f. Crumb Tire Rubber
    g. Polychloroprene latex
    h. Polychloroprene solids
    i. Natural Polyisoprene
    j. Synthetic Polyisoprene
    k. Ethylene Propylene-Diene-Monomer (EPDM)
    l. Polyisobutylene
2. Extenders
    a. Sulfur
    b. Fillers
3. Mineral Fillers
    a. Carbon Black
    b. Hydrated Lime
    c. Flyash
    d. Silica Fines
    e. Baghouse Fines
4. Natural Asphalts
    a. Trinidad
    b. Gilsonite
5. Antistripping Agents
    a. Amidoamines
    b. Imidazolines
    c. Polyamines
    d. Hydrated Lime
    e. Organo-metallics
6. Antioxidants
    a. Diethyldithio Carbamates
    b. Viscosity Modifiers
        i. Lead
        ii. Zinc
    b. Carbon Black
    c. Hydrated Lime
    d. Phenols
7. Hydrocarbons
    a. Tall Oil
    b. Aromatics
    c. Naphthenics
    d. Paraffinics/Wax
    e. Vacuum Gas Oil
    f. Petroleum/Plastic Resins
    g. Asphaltenes
8. Fibers
    a. Polypropylene
    b. Polyester
    c. Natural
    d. Glass
9. Others
    a. Gelling Agents
    b. Viscosity Modifiers

FIGURE 1 Bitumen additives currently being used or tested in pavements.

place cost of $32.00/ton of hot mixed asphalt concrete, the additives would increase the paving cost by about 12 to 28 percent. Therefore, assuming an average overlay life of 13 years, an additive would need to increase pavement life by less than 2 to 4 years to be cost-effective or decrease maintenance costs accordingly, or both. On the basis of laboratory test results and findings from the older field tests in the United States and Europe, certain polymer and microfiller additives properly applied can reasonably be expected to provide cost-effective pavement performance. Indiscriminate use of asphalt additives will not permit cost-effectiveness.

OUTLOOK FOR ADDITIVES

Vehicle weights, traffic volume, and tire pressures are steadily increasing and demanding more and more from pavement structures. Engineers are faced with serious problems regarding quality of paving material. Often materials are shipped long distances at high cost because local material supplies of high quality have been depleted. As a result, bituminous binder additives have been widely accepted by the paving industry for the present time. The concept of additives is logical, and results from laboratory testing look positive. Even though field test results using many additives are incomplete, many of those responsible for pavement quality are willing to gamble because the odds appear to be in their favor.

The bituminous binder additive industry and associated technology are advancing at a rapid rate. By the time results from the field are available for the additives being currently marketed, it is reasonable to assume that a whole new generation of bitumen additives will be on the market. It is, therefore, surmised that the outlook for additives in asphalt paving materials is excellent.

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