ADDITIVES IN ASPHALT

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Introduction

Asphalt modification has been practiced in many forms for over 150 years. Heavier traffic patterns, new refining technology, copolymer chemistry, environmental pressure to recycle waste (rubber tires, shingles), and performance graded (PG) asphalt specifications have all contributed to spectacular worldwide growth in the use of modified asphalt binders over the last ten to fifteen years. Since there is usually some economic cost associated with modification, it is important to identify the specific performance parameters that might be improved with additives or process changes.

Specific binder and mix properties can be engineered by choosing the right binder for the application, and making sure any additive used is compatible with the asphalt. The results of modifying asphalts with additives are highly dependent upon the concentration, the molecular weight, the chemical composition, the particle size and the molecular orientation of the additive, as well as the crude source, the refining process and the grade of the base asphalt used.

This paper reviews some of the different types of modifiers and modification methods, giving a historical perspective, physical properties, testing standards, field applications, comparative field trials and implications of their use. Elastomeric and plastomeric polymers, crumb rubber, special relining processing methods, oxidation, chemical catalysts and other chemical additives, gelling agents, oils and softening agents, bituminous extenders, fillers and fibers are all discussed.

Reasons to modify an asphalt binder

The National Center for Asphalt Technology (NCAT) has published a list of reasons for the use of asphalt modification. Asphalts have been modified to:

1) stiffen binders and mixtures at high temperatures to minimize rutting and reduce the detrimental effects of load induced moisture damage,
2) soften binders at low temperatures to improve relaxation properties and strain tolerance, thus minimizing non-load associated thermal cracking,
3) improve fatigue resistance, particularly in environments where higher strains are imposed on the asphalt concrete mixture,
4) improve asphalt-aggregate bonding to reduce stripping,
5) reduce raveling by improving abrasion resistance,
6) minimize tender mixes, drain down, or segregation during construction,
7) rejuvenate aged asphalt binders,
8) replace asphalt cement as an extender,
9) permit thicker films of asphalt on open-graded aggregates for increased durability,
10) reduce flushing or bleeding,
11) improve resistance to aging or oxidation,
12) stiffen hot mix asphalt (LIMA) layers to reduce required structural thickness,
13) improve pavement durability with an accompanying net reduction in life cycle costs,
14) replace PCC with asphalt construction methods that reduce lane closure times and user delay costs, and
15) improve overall performance as viewed by the highway user.

Binder/Modifier Selection and Verification:

New Superpave guidelines for binder selection and mixture performance have become one of the more important drivers for asphalt modification. Choosing an appropriate type and amount of modifier is partially driven by the PG grade selection process, which sets limits on the modulus or stiffness of the binder at high and low pavement temperatures for predetermined traffic and climatic data. Selecting the proper PG binder grade for any given project is not necessarily a simple task, but the process becomes more complex when climatic, traffic, and structural considerations force a choice among modifiers. Some of the key input variables include the following.

1. Pavement Temperature. The weather databases and computer algorithms developed by the Long Term Pavement Performance (LTTP) research team provide excellent local climatic data and statistical expectations for pavement temperatures at any depth.

2. Traffic. As traffic counts go up, as loads get heavier, and as vehicles slow down, pavements deflect further and more often. Modifiers are frequently used to "grade bump" the binder to stiffer high temperature grades to maintain rutting resistance at higher ESALs and lower speeds.

   - Modulus/Structural Value. It is crucial to consider how the modulus of the mixture made with any given binder will impact the structural value of the pavement layer in question. Engineering decisions must be made when one encounters seeming paradoxes. For example, layers deeper within the structure do not see the higher pavement surface temperatures, so the LTTP PG grade-selection program frequently recommends softer binders for base mixes. However, structural requirements may
dictate just the opposite, because stiffer base layers might reduce total pavement thickness.

- Fatigue. As the industry moves toward fundamental mechanistic pavement design systems, pavement deflection becomes an important input parameter for choosing the most cost-effective binder. Elastomeric binders and oxidized asphalt may have identical tolerance to low pavement strains, but one might observe orders of magnitude differences in fatigue life at the relatively high pavement strains typical of thinner structures. Hence, two very different modifiers can produce binders with the same stiffness at high and low temperatures, and hence the same PG grade. Will they perform the same? The answer appears to be ambiguous; sometimes yes and sometimes no. The binders cannot be accurately ranked for fatigue until the expected pavement strain has been factored into the analysis.

4. Performance Testing. The binder selection process is not complete until the resulting mixture has been verified to meet all of the mandatory performance criteria, including moduli for structural value and high temperature rutting resistance, fatigue life at predicted pavement strains, thermal cracking, moisture damage (preferably with some performance based method such as application of a cyclic load to a saturated specimen), and long-term aging. The materials engineer must recognize which modifiers will positively impact marginal performance criteria without compromising others. For example, a liquid antistrip might improve asphalt-aggregate adhesion in the presence of water, but some liquid amines might also soften the binder enough to have a negative impact on rutting. Manganese complexes or strong acids might react with the asphalt to raise the modulus at high temperatures, but improved rutting resistance could be offset by fatigue cracking from over-oxidation, or moisture damage could be accelerated by organic acids.

The American Association of State Highway and Transportation Officials (AASHTO) has recognized the need for further study to make modifier specification and use consistent with the PG grading system. The National Cooperative Highway Research Program (NCHRP) project 9-10 is charged with developing procedures and specifications which will better characterize the expected performance of modified asphalts. Although the study is still in progress, issues such as complex rheological behavior, storage stability, filler effects, and mixture properties are being evaluated for a number of different asphalt modifiers.

Polymer Modification

Introduction and Historical Perspective

Patents for modifying asphalt with natural and synthetic polymers were granted as early as 1843. The polymers are added to asphalt for a variety of reasons. They have been found to alleviate pavement problems and to realize economic, environmental, energy, application and/or performance benefits. Test projects were placed in Europe beginning in the 1930's. In North America, neoprene latex was introduced in the 1950's, and found a small but steady market, primarily in Canada and the Western United States. In the late 1970's, Europeans were ahead of the U.S. in the use of modified asphalts. The economics of higher
asphalt costs made modification costs more attractive, especially in light of the long term benefits. European transportation agencies look for innovations in technology driven by contractors, who often warrant hot mix asphalt performance. These warranties provide a financial incentive for using higher quality materials which reduce life cycle costs. Traditionally, the lower initial cost of unmodified materials has been a limiting factor in acceptance of higher quality modified asphalts in the US. In the early and mid-1980's, the use of polymer modified asphalt proliferated in the US as newer polymers were developed. European technologies were introduced, and the economic benefits of fewer early failures and lower life cycle costs became better understood.

In the early 1990's, the Strategic Highway Research Program (SHRP) developed Superpave Performance Graded (PG) asphalt binder specifications based on the pavement's temperature range. One of the primary benefits of many polymer modified asphalt binders is a reduced susceptibility to temperature. Because many of the PG's can only be met with polymer modification, it is expected that the use of polymer modified binders will increase as these specifications are implemented during the late 1990's and into the new millennium. A 1997 survey of state highway agencies found that 35 agencies reported they will be using greater quantities of modified binders; 12 agencies reported they will be using the same amount of modified binders; and 0 agencies reported they will be using less modified binders. The other important improvement imparted by the elastomeric polymers is the durability to recover from repeated loading cycles. Use of these materials is therefore also expected to rise as the increased life cycles of quality elastomer modified asphalts are factored with the ever increasing user delay costs in calculations of pavement life cycle costs.

A publication of the National Asphalt Paving Association (NAPA) lists numerous reasons for modifying asphalt cement binders and mixtures. While there are a number of different polymer modifiers used for asphalt, the improved attributes given to the asphalt depend on the chemistry and compatibility of the polymer and the asphalt being modified.

Types of Polymers

The term "polymer" simply refers to a very large molecule made by chemically reacting many (poly) smaller molecules (monomers) to one another in long chains or clusters. The physical properties of a specific polymer are determined by the sequence and chemical structure of the monomers from which it is made. When polymers are added to asphalt, the properties of the modified asphalt depend on two things: 1) the polymer system used and 2) the compatibility of the polymer with the asphalt.

Although polymers can be formulated to yield a virtual continuum in physical properties, those used most often in modifying asphalt can be grouped in two general categories: elastomers and plastomers. Elastomers can be stretched and elastically recover their shape when released. Such polymers add only a little strength to the asphalt until they are stretched. But they get stronger as they are pulled out of shape, and they recover when released, much like a rubber band. Plastomers form a tough, rigid, three dimensional network. These polymers give high early strength to resist heavy loads, but may crack at higher strains.
Latex is a term for a water based emulsion of polymer droplets. The type of polymer in latex can vary widely. Because of the ease of incorporating the water-based latex into water based asphalt emulsions, chip seals and slurry seals were some of the first paving applications to take advantage of polymer modified asphalt.

Polymers made from two or more different monomers can also be characterized as random or block co-polymers. In block co-polymers, a polymer of one monomer is chemically reacted to a block of another monomer. An example is SBS (styrene-butadiene-styrene), which is made up of a block of polystyrene chemically combined with a block of polybutadiene and another block of polystyrene. In a random polymer, the monomers are randomly mixed in the polymer chain. SBR (styrene-butadiene rubber) is an example of a random polymer. It is composed of the same monomers as the SBS, but its random orientation gives different physical properties. The physical properties are also dependent upon the size and physical orientation of the polymer.

Specific binder and mix properties can be engineered by choosing the right polymer for the application. and making sure it is compatible with the asphalt. In general, elastomers are chosen to give a more resilient, flexible pavement, while plastomers result in mixes with higher stabilities and stiffness moduli. The results are highly dependent upon the concentration, the molecular weight, the chemical composition, and the molecular orientation of a particular polymer as well as the crude source, the refining process and the grade of the base asphalt used.

Elastomers

Elastomeric polymers are characterized by their ability to resist permanent deformation and cohesive failure by stretching, and then recovering their shape when the deforming force is removed. Consider the analogy of a rubber band. At low tensile strains, an elastomer exhibits little strength. The stiffness of an asphalt mixture as measured by resilient modulus (a non-destructive low strain test) should be similar to that of a comparable mix made from the same base asphalt. Since the tensile strength of the elastomer increases with elongation, one must use dynamic tests which measure accumulated shear strain over a number of cycles to fully understand the value of elastomer modification in HMA.

There are several different types of elastomeric polymers used for modification of paving asphalts. Natural rubber or isoprene latex, one of the materials mentioned in the earliest patents, is still being used today, primarily in water-based emulsion applications such as Micro-surfacing. Neoprene is the generic name for elastomeric polychloroprenes (dichloro-l, 3-butadiene), which may be added in either dry or latex form. Neoprene modified asphalts have been used for many years, but have more recently been replaced by other types of elastomeric polymers. Water based styrene-butadiene rubber (SHR) latex has found wide usage as an additive to emulsions to improve chip retention. This technology continues to improve, as manufacturers are formulating both the polymer and the latex emulsion additives specifically for asphalt modification.
The new latex materials are also being incorporated into hot mix asphalt, using various processes to flash off the water. Preblending infers that the latex and asphalt have been mixed at a central location using a batch process. In-line injection implies that the latex and asphalt are blended immediately before being applied to the aggregate at the hot-mix plant. In some cases, the latex may be applied directly to the aggregate through a separate spray nozzle. This last method is particularly appropriate when the latex is applied in a separate drying step for antistrip purposes. Advantages to latex preblending are: 1) polymer and asphalt are thoroughly mixed, so that mechanical properties are more uniform; 2) polymer has time to swell in the asphalt, which usually improves mechanical properties; 3) water vapor from the latex cannot cause steam distillation from the asphalt at the hot plant releasing volatile organic compound (VOC) emissions; and 4) binders can be tested and certified before application to the aggregate. Disadvantages of preblending are 1) potential separation of polymer and asphalt during transportation and storage of incompatible materials, 2) higher handling costs, and 3) the need for an asphalt storage tank for the polymer modified asphalt cement (PMAC).

Styrene-butadiene (SB/SBS) block copolymers have gradually replaced latex use for many modified asphalt paving applications. Block co-polymers have greater tensile strength at strain than the randomly reacted SBR, and they are typically compatible with a broader range of asphalts. Varying molecular weights, chain lengths of the styrene and butadiene blocks, vinyl content in the butadiene, and spatial configuration of the blocks (diblock, linear, radial, star) result in a variety of SB and SBS polymers used for modifying asphalt. These factors influence the compatibility and the ultimate physical properties and therefore field performance of the modified asphalt. A number of commercial products have overcome some of the more difficult compatibility problems by chemically cross-linking polymers to asphalt in-situ, or by adding oils and chemical stabilizers which compatibilize the system through physical interactions.

Other elastomers include polyisoprene, polybutadiene, a wide range of copolymers such as styrene-isoprene-styrene (SIS), styrene-ethylbutylene-styrene (SEBS), functionalized copolymers such as carboxylated SBS; terpolymers, and now complex polymers with various functional groups (glycidyl, acrylate, esters, etc) placed on plastomeric ethylene backbones which combine to exhibit physical properties more characteristic of elastomeric behavior. Some of these functional groups, such as epoxide rings, are themselves reactive and initiate further chemical reactions with asphalt molecules when heated.

Plastomers

The rigid, three dimensional network of plastomers impart quick early tensile strength under heavy loads. Mixtures made with plastomers should exhibit high moduli in low strain tests such as resilient modulus. However, high early tensile strength usually is coupled with lower strain tolerance. At the higher pavement strains observed, for example, in thin structures or over concrete joints, fatigue or reflective cracking can occur.

Plastic additives used in flexible pavement construction are generally polyolefins such as polyethylene, polypropylene, or co-polymers of polyolefins. Amorphous polyethylene are
used for asphalt modification, but even then the longer aliphatic chains can coalesce and crystallize over time causing physical hardening. Polyolefins are typically incompatible with asphalt and separate quickly in heated storage. Some novel chemical systems which stabilize amorphous polyethylene in asphalt have recently been commercialized.

Numerous ethylene copolymers, such as ethyl vinyl acetate (EVA), ethyl methacrylate (EMA), and ethyl butyl acrylate (EBA) have been further developed for asphalt modification. These comonomers add some elastomeric characteristics to the plastomeric polyethylene backbone and greatly improve the polymers compatibility with asphalt cement. At low temperatures, the copolymers are intended to improve resistance to thermal cracking by inhibiting the propagation of cracks.

Polymer Identification

Chemical and physical tests are used to identify the presence of polymer in modified asphalts. Spectroscopic methods such as infrared spectroscopy (IR) and nuclear magnetic resonance (NMR) are used qualitatively to identify the presence of chemical bonds specific to polymers. These methods have also been used for quantifying and specifying weight percent of additives. Texas, Kansas and Arkansas have used an IR determination of butadiene content to specify SB(S) modified asphalts for both hot mix binders and emulsion residues. In this method, the producer provides samples of the unmodified asphalt and the polymer so that a calibration curve can be developed. If a different base asphalt is used, the calibration curve must be revised. These methods identify the presence of the polymer, but do not characterize the enhancement of properties, which vary with the compatibility of the asphalt and the polymer used. Instrumental methods such as IR have created some complications in PMAC specifications, particularly when the chemistry of the asphalt impacts the test results. Crudes coming through pipelines are notoriously inconsistent, and refineries must alter crude slates frequently as economic incentives and product needs change. Construction delays can occur when unexpected crude changes necessitate lengthy laboratory recalibration procedures before the liquid PMAC can be certified for shipment.

The molecular weight and the physical size of polymers used in modification are being characterized by the use of high performance gel permeation chromatography (HP-GPC). Typically, the elastomers used for polymer modification are much larger molecules than those found in paving grade asphalts. It is possible, although not always simple, to separate the polymer from the asphalt using these methods.

Asphalt Compatibility

The morphology and networking of the polymer within an asphalt determines its physical properties. Several microscopy techniques, including reflective fluorescence, scanning and electron transmission, have been used to determine the polymer-asphalt microstructure and relate that microstructure to physical properties. It is generally concluded that the compatibility between a given asphalt and a given polymer can have dramatic effects on the high
temperature, low temperature and fatigue behavior of the finished product. Blending the same polymer with asphalts from two different crude sources may give very different physical property and ultimate performance results. Similarly, two different polymers blended with the same asphalt will not provide equivalent property enhancements.

Polymers can be swollen by the oily fractions of the asphalt, can network within the asphalt, can "ball" up and form discrete domains, or can be simply sheared into very small particles dispersed in the asphalt. The best performance is provided when the swelling and networking occurs. If the polymer is merely dispersed, it will have a tendency to separate. Most elastomers have a significantly lower specific gravity than asphalt, resulting in migration of the polymer to the surface. Various tests have been developed, most notably the polymer separation test specified in the Type I specifications as published by Task force 31, a joint effort of the American Association of State Highway and Transportation Officials (AASHTO), the Associated General Contractors (AGC) and the American Road and Transportation Builders Association (ARTBA). The newly developed Long-Term Asphalt Storage Stability Test (LAST) represents a much more sophisticated evaluation of thermal degradation and potential separation during storage. (4)

Sensitivity to thermal history is another important consideration when characterizing PMACs. Less compatible systems can be well-dispersed under agitation and maintain a strong networked structure with excellent physical strength if cooled rapidly. However, this same blend, if cooled slowly, may separate and yield inadequate performance. "This effect can be demonstrated quite dramatically through changes in the ring and ball softening point. As one example, an incompatible SBS/asphalt blend exhibited a reduction in softening point of 40°C when the ring was cooled over a period of two hours on a heated steel plate rather than cooled per the standard procedure.

Physical Properties of Polymer Modified Asphalt Binders Conventional Testing

Polymer modified asphalts show varying effects when conventional asphalt tests are conducted. Typically, the viscosity of both elastomeric and plastomeric modified asphalts at 60°C will rise significantly, while penetrations of elastomeric modified materials at all temperatures only change slightly. If the polymer contains an extender oil, the penetration will normally be lower than the unmodified asphalt, while the viscosity at 60°C: may double or triple. These high viscosities have created confusion when predicting mix and compaction temperatures using standard temperature-viscosity charts. PMACs can often be pumped and mixed at temperatures lower than those predicted by conventional Marshall mix design practices. The very high viscosities can also be misleading predictors of performance. Studies have shown that at high polymer levels, viscosity over-predicts relative resistance to rutting, whereas results from the dynamic shear rheometer (DSR) rank elastomer modified asphalts in good correlation to laboratory wheel tracking results.

Elastomers also have a marked effect on the ductility test at both intermediate (25°C) and low (4°C) temperature. Neoprene and SBR latex modified asphalt have very high ductilities at all temperatures, while many SB or SBS modified asphalts have lower ductilities. In the latter case, the materials fail not because of a loss of strength, but because of too much strength.
Instead of pulling to a very thin thread that eventually breaks, the elongated samples are very thick and snap in the same mode as a thick rubber band that is pulled too far.

Some commercially available modified asphalts require constant agitation to keep the polymer homogeneously suspended. When these materials are tested, the polymer segregates from the asphalt during the sample conditioning process, which may give results that are not representative of the material as used. Non-homogeneity may also cause poor repeatability of laboratory results.

Binder Test Procedures Specific to Polymer –Modification

Several test methods specific to polymer modified asphalts have been adapted or developed to identify the enhanced properties and to allow specifications to be written which differentiate unmodified and modified materials. The softening point by ring and ball apparatus (ASTM E 28), primarily used for specifying asphalts for roofing, has been used for polymer modified paving asphalts to demonstrate the resistance to flow at high temperatures. This test is widely used in Europe for paving asphalts. Similarly, a flow test at elevated temperature (ASTM D 1191) specific to polymer modified asphalts for joint sealants was developed.

Toughness and tenacity was an early test to measure the tensile strength during elongation of neoprene modified asphalts, and is still used in some specifications. The Europeans refined tensile testing of asphaltic binders by adapting a test commonly used in the rubber industry, "Test Methods for Rubber Properties in Tension" (ASTM D 412). This test, which measures the force over a defined cross-sectional area, was used by some states in specifications for early SB(S) block co-polymer modified asphalts and emulsions in the U. S. A force ductility test was developed to measure tensile properties using a less expensive force adapter in a standard ductilometer.

One of the benefits of elastomer modified asphalts is their ability to elastically recover from deformation. A torsional recovery test was developed by Thompson and Hagman, and is in specifications in California and other locations as a field test to identify the presence of elastomers, especially in latex modified emulsion residues. The Australian sliding plate rheometer, concentric cylinder deflectometers and other rheological devices have been used to measure the creep resistance and elastic recovery of modified binders. An elastic recovery after ductility test, also included in the Task Force 31 specifications has been widely accepted in the U.S. and Europe for SB(S) modified asphalts and emulsion residues.

Performance Based Testing Including Superpave

As the number of different modifiers and suppliers proliferated, so did the test methods and specifications. Some, such as the IR, are "recipe" specifications where the percent of polymer is specified. Others, such as low temperature ductility and torsional recovery, identified the presence of certain types of elastomers. To gain the most value from the modification, however, it is the performance, not the presence of the modifier, that should be measured. The West Coast User Producer Group attempted to specify performance with the PBA (performance based asphalt) specifications, which used a viscosity test at high temperature
and a penetration or ductility test at low temperature to define the temperature susceptibility of the binder after it has gone through rolling thin film oven aging simulating the hot mix process. The idea was to write specifications that are blind to the type of modification used. While these conventional tests conducted on straight-run asphalt correlate satisfactorily with performance, the relationships are not as clear for modified binders.

The Strategic Highway Research program (SHRP) was charged with developing performance based specifications. These tests and specifications have been adopted by AASHTO. The dynamic oscillatory shear test at high temperature for resistance to rutting has been found to have better correlation to laboratory rutting tests than do the standard viscosity tests. At low temperatures, the bending beam rheometer shows much better agreement with thermal stress restrained specimen test (TSRST) laboratory mixture cooling results than did traditional low temperature penetration, ductility, or Fraass. The concept of using the DSR at intermediate temperatures to measure dissipated energy ($G''$) has not yet proven to be a reliable ranking test for fatigue resistance and is being studied. A proposed direct tension test is expected to demonstrate and quantify the low temperature performance. Many researchers are studying the response of modified binders to the SHRP developed test methods, and recent reviews on this subject are available.

If the ultimate objective is performance based specifications covering a broad range of climatic and pavement loading conditions, it is always helpful to develop rheological models which predict a broad range of binder performance properties from a few simple tests. Recent work by Zanzotto reviews the excellent asphalt rheological modeling work done by Anderson and Christiansen and then applies stretched exponential relaxation functions to more accurately model polymer modified asphalts.

A field and laboratory study in Kentucky found that PG 70-22 fabricated by a number of different modification methods did not give the same results in all laboratory tests. NCHRP project 9-10 has proposed a separate testing protocol for binders characterized as simple and complex. The rationale is that many modified binders are rheologically complex, and do not meet assumptions made in the development of the Superpave performance graded binder test methods. Those assumptions include a limited strain dependency, no thixotropy, homogeneity, and no additives (particulates) that result in geometric effects.

Impact on Laboratory Mixture Properties

While different modifiers and their morphology within the asphalt give very different physical properties, most elastomer modified asphalts are both more cohesive and more adhesive than unmodified asphalts. That means that the materials seem "stickier" and string during handling. To prevent problems during sample preparation, the appropriate temperature range should be used. Because of the non-Newtonian rheology of many of these binders, that temperature range is not the same as would be predicted by standard viscosity tests. Superpave specifications recommend consulting the supplier for recommended laboratory and field handling guidelines, including storage, mixing, and compaction temperatures. Many polymers will degrade at temperatures above approximately 200°C, so transportation and storage above those temperatures for any period of time should be avoided. Different thermal
transfer coefficients may mean it takes longer to heat and cool tanks. Agitation may help distribute heat evenly throughout the sample.

If a material is not homogeneous, it is necessary to keep it under constant agitation. Some unstable materials may separate during repeated heating and cooling cycles.

Production and Placement Guidelines

Studies have shown that construction of polymer modified asphalt cement pavements can use conventional procedures. As in laboratory handling, modified binders may require higher temperatures, depending upon the modifier used. Pumping and handling the liquid binder is normally not a problem so long as the Brookfield viscosity is below 3000 cSt at 135C. Highly modified asphalts with kinematic viscosities above 3000 cSt have been placed successfully, but pre job test strips are recommended to ensure that acceptable compacted densities can be achieved. When a material is not homogeneous, it will need to be continuously agitated to prevent segregation. Supplier recommendations should be followed for storage and handling guidelines.

Field experience has shown that it is important to respect the recommended temperature range for mixing, laydown and compaction because of the increased cohesion and adhesion of the modified asphalt. When the materials are not hot enough, viscous slugs may form at cold spots. Because of the increased adhesivity, handwork has been found to be a little more difficult, especially when working at marginally low temperatures. Likewise, special "release agents" are often applied to truck beds to prevent sticking. Rubber-tired rollers have a tendency to "pick-up", particularly when the tires are cold. Sticking problems can be greatly reduced by using liquid soap in the roller water and by allowing the surface of the mat to cool before rolling with rubber. Steel-wheeled rollers are often preferred for compacting modified hot mixes.

Paving Applications for Polymers

Polymer modified asphalts have been used in virtually every paving application. Their greatest benefits are derived where conventional asphalts have not given satisfactory performance, or when they are used at high stress locations that are difficult to reach or expensive to shut off to traffic during construction. Polymer modified binders are most often selected for use in locations with temperature extremes. The improved rheological characteristics including resistance to flow have led them to be the binder of choice for open-graded mixtures such as open-graded friction courses (OGFC) and stone matrix asphalt (SMA) which require thicker films of asphalt on the aggregate to resist draindown and raveling. Modified materials have also found wide use on highly stressed applications such as intersections on busy city streets, airports, truck weigh stations, and race tracks. The use of polymer modified binders can reduce the design lift thickness, especially when used for maintenance or crack retardation over structurally sound pavements. Dense graded hot mix, hot applied surface treatments, stress absorbing membranes, joint sealants and patch mixes have all benefited from the elasticity and adhesion imparted by the elastomers.
Elastomeric polymer modified asphalt binders help restore and can improve the integrity of materials when added during both hot and cold recycling.

Elastomer modified emulsions have been used extensively to improve adhesion of chip seals and the durability of slurry seals. A special process using a polymer modified emulsion applied immediately before a thin layer of gap-graded hot mix has found commercial success in Europe and the U.S. because of the speed of construction, improved skid resistance, improved bonding to the existing surface, improved resistance to raveling, and ultra-thin lift leaving overhead clearances and curbs undisturbed. Micro-surfacing, a new slurry technique incorporating elastomeric polymers, can be placed at greater thicknesses than conventional slurry seals, allowing their use for rut-filling. Micro-surfacing is becoming an important technique for cost-effective preventive maintenance. Elastomer modified emulsions are also used for tack emulsions, stockpilable patch mixes, cold mixes, crackfillers, and in-place recycling.

Field Performance - Research Field Trials with Polymer Modified Asphalts

Numerous experimental field projects comparing modified and unmodified asphalt binders in hot mix asphalt and in emulsions for maintenance applications have generally concluded that elastomeric polymers improve performance at low and high temperatures and the modified materials can reduce life-cycle costs. There is no lack of reports in the literature on comparative field trials, from places as diverse as Texas, Michigan, California, and Australia. Recent projects in Maryland and Colorado determined elastomer modified hot mix asphalt (HMA) in a high quality mix design results in substantial life cycle cost savings for busy intersections. A similar study showed that Micro-surfacing is a cost-effective solution to maintenance. The industry is continuously developing and improving polymer modified binders. As highway engineers are seeking better, more cost-effective ways of building and maintaining highways, polymer modified binders have become one of their options.