HYDRATED LIME — MORE THAN JUST A FILLER

Hydrated lime has long been recognized as a highly beneficial component of hot mix asphalt, based initially on its ability to reduce stripping. Subsequent research and experience have demonstrated that lime’s benefits are much broader, and include:

- Increased mix stiffness and reduced rutting.
- Reduced oxidation and age-hardening effects.
- Improved low-temperature cracking resistance.

This paper describes these benefits in more detail, based on recent research pursuant to Strategic Highway Research Program (SHRP) standards.

BACKGROUND

Before SHRP, bitumen binders were generally classified according to either penetration grading or viscosity grading, with viscosity grading eventually becoming predominant. In the early 1980s, the SHRP standards were established in order to develop a new grading system that would better take into account America’s diverse climatic and traffic conditions. The asphalt portion of SHRP cost fifty million dollars, and engaged the best asphalt technology researchers, and included participation in technical committees by representatives of all facets of the highway asphalt industry. The process culminated in a radical reassessment of tests for binders and Hot Mix Asphalt (HMA), and a new system of grading bitumens, known as “performance-grading,” (PG). The designation PG 64-28, for example, is intended for an area of the country in which the average seven-day maximum pavement temperature would be 64°C and the minimum pavement temperature expected would be -28°C. Bitumen properties were required to meet a series of tests. SHRP also resulted in the Superpave mix design method for HMA.

STIFFNESS AND RUTTING

A key element in the performance of a bitumen is its stiffness and resistance to rutting. As shown below, the addition of hydrated lime significantly improves the performance of SHRP bitumens in this regard.

Asphalt technologists have long since considered bitumen as being a viscoelastic material, implying that it had the dual functions of being viscous (i.e., it could flow under an applied load) and of being elastic (i.e., it could tend to recover its previous form when the applied load was removed). Temperature and rate of loading affect the viscous and elastic behaviors. Through SHRP, an effort to account for these two components and the countrywide temperatures under which highways must perform resulted in the Dynamic Shear Rheometer for testing bitumens and modified bitumens. The procedure requires torsion to be applied to a thin disc of asphalt binder or modified binder at a specified temperature. A parameter (G*/sin *) is derived from the procedure and is taken to be an indicator of resistance to rutting. G* is a modulus, a measured property of the viscous and elastic components of the binder used in the test. The * value characterizes how viscous or elastic the binder is. Two different bitumens or modified bitumens might have the same value of G* but behave differently.

Figures 1 and 2 below show the concept diagrammatically [FHWA, Background of Superpave Asphalt Binder Methods (FHWA-SA-94-069)].

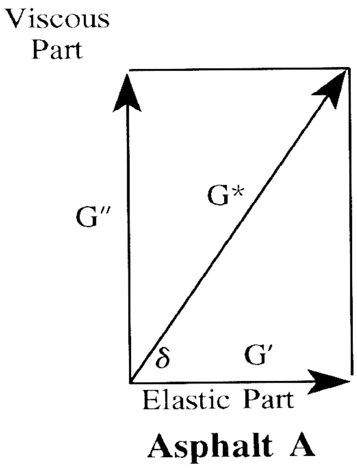


Figure 1

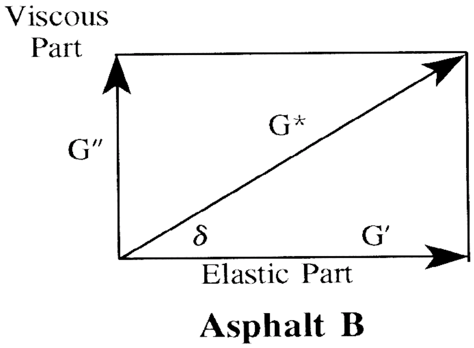


Figure 2

Research has been performed to measure the effect on resistance to rutting of adding hydrated lime to bitumens. The accompanying figure below shows the improvement in G*/sin * for five SHRP bitumens by modifying them with 20% hydrated lime, which would amount to about 1% to 1.5% of hydrated lime in an HMA. As can be seen from the graph, the addition of hydrated lime will produce a binder with significantly better resistance to rutting than unmodified bitumens.

High temperature rheological data for SHRP bitumens (64C):

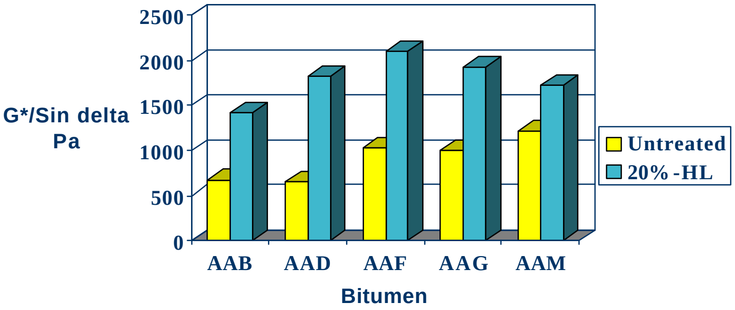


Figure 3

In addition to tests on bitumens, compacted HMA samples can be tested for resistance to rutting by cycling a loaded wheel on the specimen. Typical of this approach are the Georgia Rut Tester and the Hamburg Wheel Tester. In the figure below, using the Georgia Rut Tester, the number of cycles to produce a specified rut depth (7.5 mm) is much greater for the mixes with hydrated lime than the unmodified mixes. In practical terms, this means that the pavements would carry more traffic before rutting to the degree experienced by the unmodified mixes.

Georgia rut tester (40C) on mixes subjected to vacuum saturation

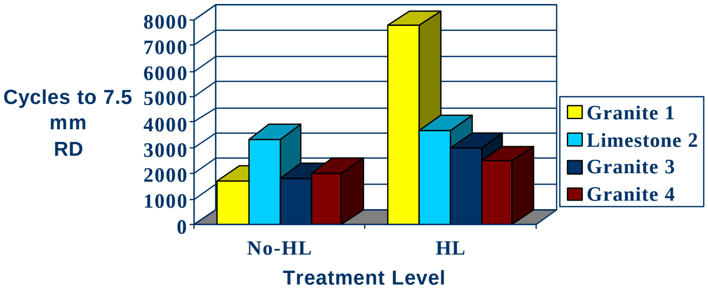


Figure 4

Permanent deformation (rutting) of HMA can be represented by a relationship in which the permanent strain increases at a rate that is dependent on the mix properties. The rate of accumulation of permanent strain decreases with increasing load cycles and, depending on the mix properties, tends to be a limiting value. The process of reduced rate of accumulation of permanent strain with loading is called strain hardening. However, some mixes exhibit an increasing rate of accumulated permanent strain — referred to as tertiary damage. Figure 5 below is a diagrammatic representation of the concept.

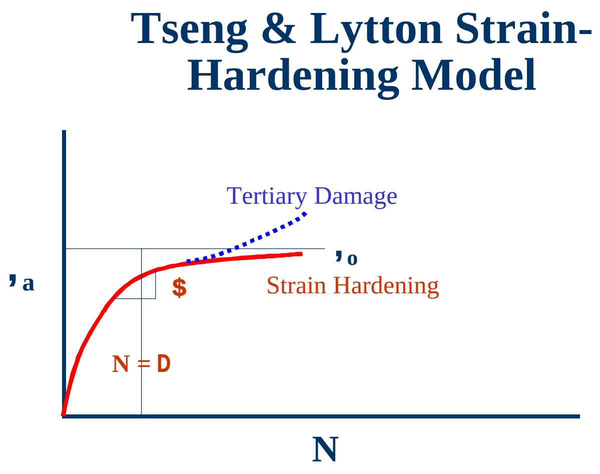


Figure 5

Plotting the rate of strain hardening against the number of loading cycles gives a relationship graphically represented below.

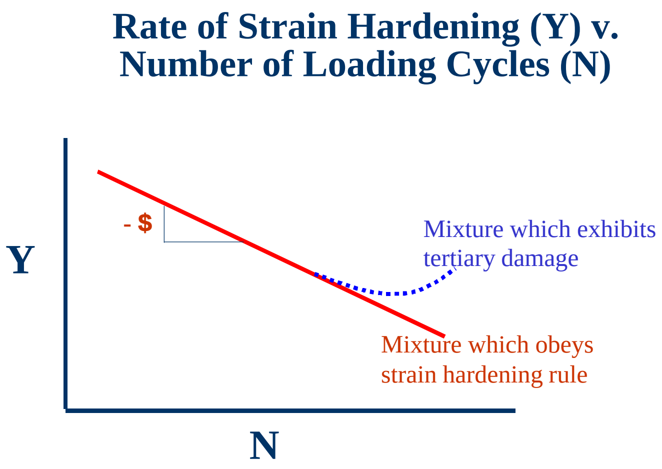


Figure 6

Extending this concept to an example in which SHRP asphalt AAD was compared with mixes containing various percentages of hydrated lime (using natural log scales) shows an upward trend in mixes suffering tertiary damage. Stable mixes are clearly demonstrated. This technique can be a valuable tool in assessing the effectiveness of different additives. In the example shown on Figure 7, the addition of hydrated lime to the mixes with AAD bitumen clearly stabilized the mixes and prevented tertiary damage.

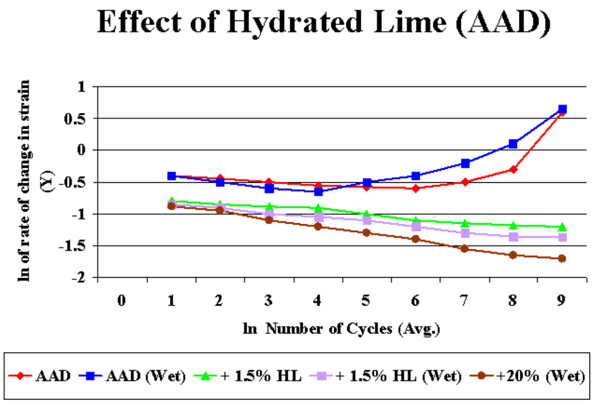


Figure 7

In sum, addition of lime to bitumens significantly improves the performance of those bitumens, as well as the HMA itself, in terms of resistance to rutting and deformation.

MOISTURE AND STRIPPING

Stripping is a form of pavement distress which is manifested by separation of the binder from the aggregates in the matrix. Hydrated lime has long been used as an anti-stripping additive to HMA, and research shows that it remains the most effective choice.

Water, being a known enemy of all types of pavements, is the usual suspect in stripping. Poor drainage may allow water to enter the pavement structure from the sides. Cracks in the surface may allow ingress to the base and subgrade, causing loss of support. Surface stripping results in ravelling. Substructure moisture can penetrate the pavement in the form of moisture vapor, rising through minute fissures and interconnected voids or larger cracks. In doing so, the moisture vapor can strip the binder from the aggregate particles. The structure loses strength as its cohesion diminishes and failure is accelerated.

In general, aggregate properties dominate the moisture susceptibility of an HMA. The physicochemical surface properties of the aggregate play a much larger role in stripping of HMA than the properties of the asphalt cement binder.

Moisture-damage problems in the United States in the late 1970s induced a flurry of research and resulted in a number of new test methods:

- Loose (uncompacted HMA) samples, including soaking and boiling tests (e.g., ASTM D 3625)
- Representative mix category in which a representative portion of the aggregate (e.g., the fine aggregate) is tested. An example is the "pedestal freeze-thaw test."
- Compacted mix tests such as ASTM 1075, ASTM 4867, and AASHTO T 283.

Most of the liquid antistripping additives are surface-active agents such as amines. They are usually mixed with the asphalt cement prior to pumping the modified binder to the mixing plant. Effectiveness of the additive can be compromised if the additive is not heat stable because it can deteriorate while the asphalt binder is kept in storage at elevated temperatures. Although easy to mix with the asphalt cement, the method is inefficient. The application rate of liquid antistrip agents is typically 0.5% by mass of asphalt cement and only a portion of it can actually reach the asphalt/aggregate interface.

The most widely used antistrip additive is hydrated lime. It has been used as a filler in HMA for at least 80 years although its benefits as an antistrip material may not have been recognized in the beginning. Figure 8 below shows an effectiveness rating for various antistrip additives. Hydrated lime clearly has a better rating than liquid antistrip agents, polymers, and portland cement.

Relative Effectiveness of Additives in Eliminating or Reducing Moisture Damage Susceptibility (After Hicks)

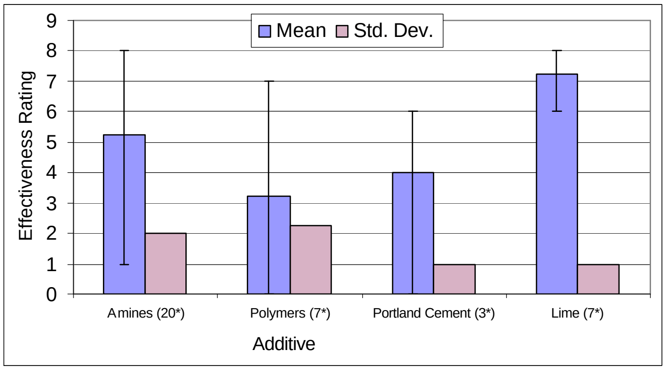


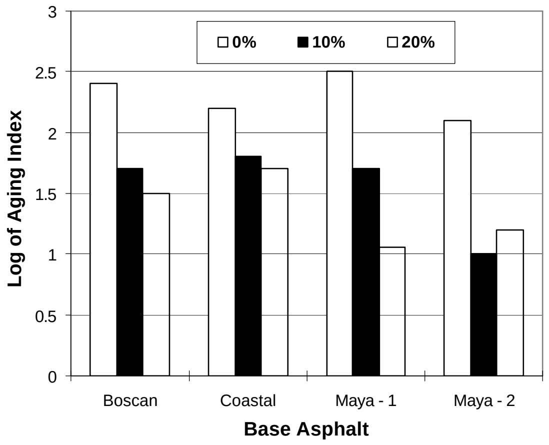
Figure 8

Thus, hydrated lime continues to be the most effective option in dealing with the stripping associated with exposure of HMA to moisture.

AGING AND FATIGUE CRACKING

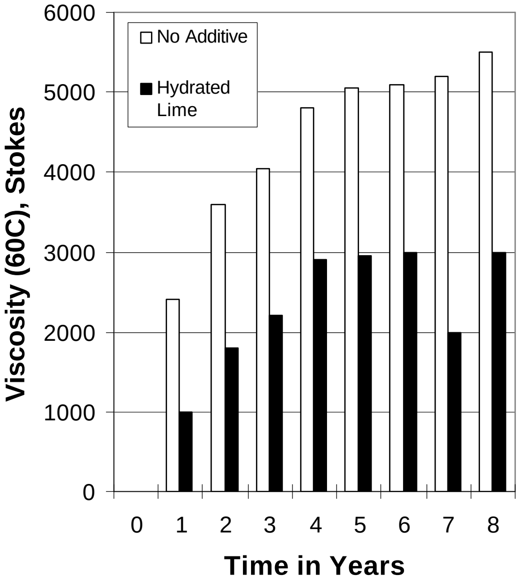
Asphalt cement is not immutable. It can and will change its properties under some circumstances. Time, air, elevated temperatures in storage and thin films in the presence of heat and air in the hot mixing process expose the binder to risks of oxidative change. In service, asphalt pavements suffer from weathering and aging, some more quickly than others and for many reasons. Hydrated lime in HMA, however, acts not merely as a filler, but also improves aging properties. There is a physicochemical interaction between hydrated lime and bitumen, producing multiple benefits, one of which is a reduction in oxidative hardening. Research has shown that as little as 0.5% hydrated lime in HMA will achieve a reduction in oxidative hardening.

Tests have been developed to simulate binder aging (hardening) during HMA production, construction and service life. The binder becomes harder as its viscosity increases through aging. It loses ductility and becomes brittle. Thin film tests were developed in the late 1950s and 1960s to simulate changes in properties of bitumens during the HMA production process. These were the Thin Film Oven Test (TFOT) and the Rolling Thin Film Test (RTFOT). Further tests, such as the Thin Film Accelerated Aging Test (TFAAT) and more recently SHRP’s Pressure Aging Vessel (PAV) were developed to simulate aging in service. The results from such tests indicate the degree of severity of changes in the binder. An aging index (usually based on changes in viscosity) can be derived from such investigations. Figures 9 and 10 show examples of investigations and indicate the favorable use of hydrated lime. In most cases in the study reported by Peterson et al., 20% hydrated lime in the bitumen (i.e., equivalent to 1% in an HMA containing 5% bitumen) was the optimum amount.



Effect of Hydrated Lime in Reducing Aging Index of Asphalt Binders (after Peterson et al.)

Figure 9



Field Data Demonstrating the Effect of Hydrated Lime on the Hardening of Asphalt Binder based on Utah Data (after Jones)

Figure 10

Cracking of asphalt pavements can occur from many causes, not merely because of aging. One type of cracking is fatigue cracking which is caused by an inadequate structural design and an inappropriate mix design for the applied loads — heavy loads or many repetitive light loads can bring about the distress. Figure 11 below shows results from a study at Oregon State University for the Oregon DOT. This work clearly demonstrated the fatigue superiority of hydrated lime in the HMA.

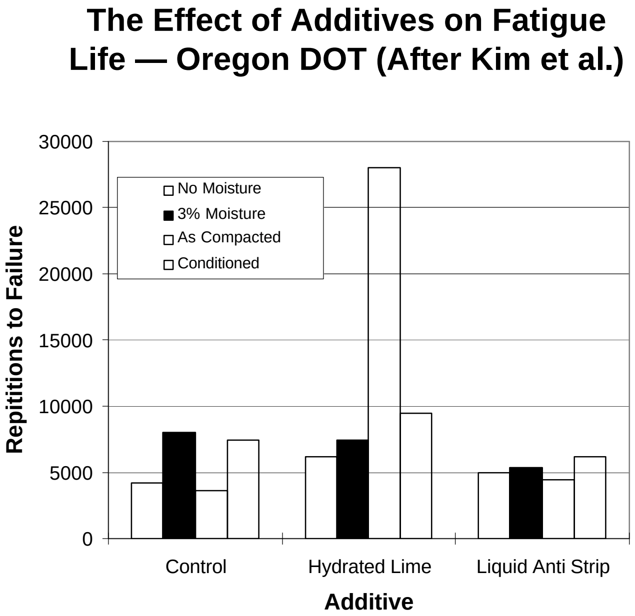


Figure 11

Currently, a part of SHRP's PG specification for an asphalt binder uses the previously mentioned G* and sin * to control fatigue cracking. However, the parameters are multiplied this time and the test is performed on the binder after TFOT and PAV aging to give a maximum allowable value. The addition of hydrated lime to bitumen stiffens the bitumen because of the filler effect. Excessively stiff mixtures can, however, suffer from fatigue. Nevertheless, a compensatory reduction in fines can partially offset the stiffening effect of the hydrated lime.

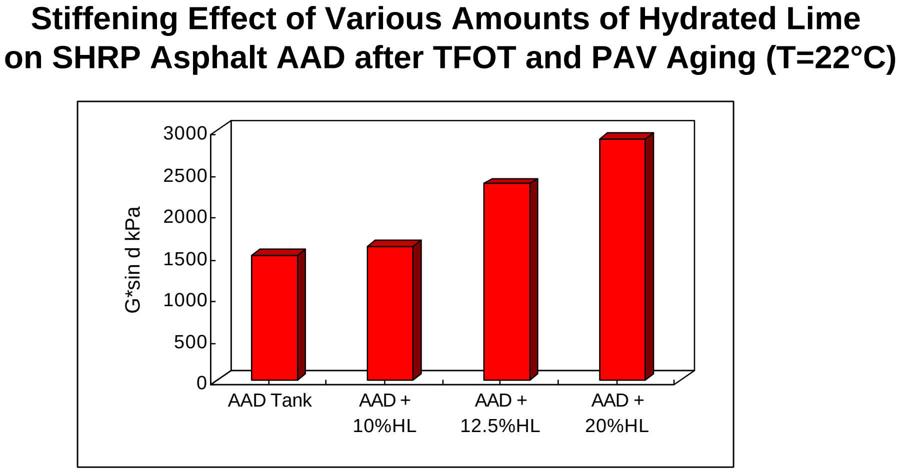


Figure 12

In a recent study, fatigue testing on dense-graded mixtures of crushed limestone aggregate and two SHRP bitumens was conducted with and without the addition of hydrated lime and with aging of the samples before testing. Cylindrical samples were molded and subjected to repeated direct tensile loading. The results showed that hydrated lime (added as a filler to the bitumen as a replacement for an equal amount of limestone filler) had a mild effect on mixture stiffness but a significant effect on fatigue life. The diagram below is taken from a series of results from the study. Note that the stiffness of the bitumen is virtually unaltered, but that the fatigue life is vastly improved. This study on cyclic tensile fatigue testing concluded that crack-pinning and reduction in age-hardening of the bitumen were enhanced through the addition of hydrated lime.

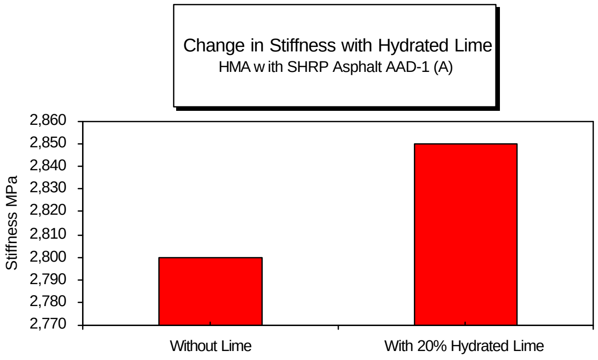


Figure 13

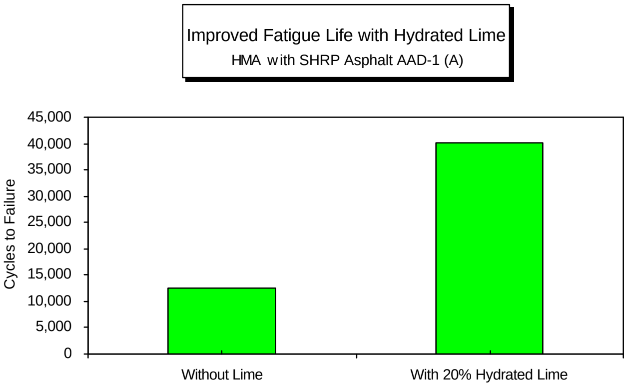


Figure 14

Recently, fatigue life has been investigated using a controlled strain torsion test on the mastic (bitumen and fines) of HMA. Using a dynamic rheometer, fatigue damage is measured as a reduction in stiffness of the mastic, typically defined as the value of G* at which a 50% reduction occurs. It is suggested that this too is a useful tool for mix design purposes.

LOW TEMPERATURE CRACKING

In cold climate areas, HMA can suffer from low temperature cracking. Hydrated lime is also useful in addressing this problem. SHRP's PG specifications attempt to cover this by a rheological test using a Bending Beam Rheometer (BBR). In the BBR test, a load is applied to a beam of asphalt binder or modified asphalt binder under controlled temperature conditions. Deflections of the beam are noted during the loading cycle and a parameter (Creep Stiffness, S) is calculated after 60 seconds along with the rate of change of stiffness (m-value) at that time. The shortness of the actual loading time to arrive at the S and m-values is a laboratory convenience and was arrived at after some correlation with much longer loading times. Furthermore, some binders (particularly modified binders) may have creep stiffness values higher than specified but do not crack because they can stretch further without breaking. To accommodate them, SHRP includes a Direct Tension Test (DTT). This is a type of low-temperature ductility test.

The low-temperature benefits of hydrated lime in HMA are most evident from tests on the mixture. Such tests evaluate the effect of the hydrated lime as a crack-arresting system, which promotes fracture toughness in the filled system. The crack-arresting mechanism is commonly believed to depend on mineral filler particles in HMA intercepting microcracks, deflecting them and preventing them from developing into wide cracks.

Hydrated lime generally increases the stiffness of bitumen at low temperatures. However, the level of increase in stiffness at low temperature is not nearly as significant as the effect at high temperatures. Figure 15 below shows SHRP asphalt AAM tested at -12°C and with 10%, 12.5%, and 20% hydrated lime.

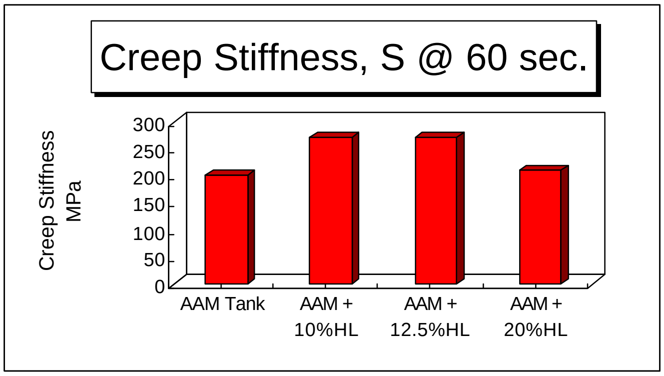
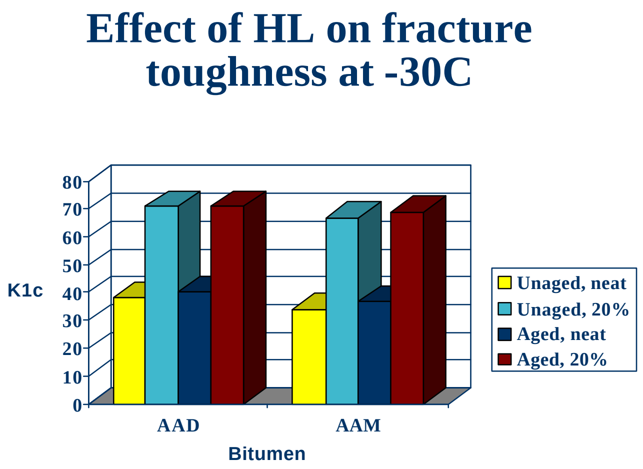


Figure 15

In the above figure, the changes in stiffness of the SHRP asphalt AAM with hydrated lime are modest.

Fracture toughness testing on an Instron 1125 tensile machine, following a procedure in ASTM E 399-90 revealed interesting comparisons on SHRP bitumens with and without 20% hydrated lime and before and after TFOT and PAV aging. Hydrated lime clearly improves the fracture toughness of the bitumens as shown in Figure 16.



Effect of HL on fracture toughness at -30C

Figure 16

RECOMMENDED IMPROVEMENTS TO ASPHALT MIXTURE TESTS TO BETTER SIMULATE LONG-TERM PAVEMENT PERFORMANCE

A number of tests have been developed to measure the properties of asphalt mixtures. Unfortunately, current tests do not adequately simulate long-term performance. The following discussion (1) summarizes current tests to evaluate the effects of moisture, repeated loading, aging, and fatigue; and (2) recommends changes to better simulate long-term performance and improve mixture design, consistent with planned changes to the 2002 AASHTO Pavement Design Guide.

MECHANISTIC TESTS TO EVALUATE DAMAGE

To accurately evaluate the ability of an asphalt modifier to improve long-term performance requires mixture tests that simulate the cyclic damage induced by traffic, accumulated strain, the effects of moisture, age hardening, and fracture growth. Monotonic loading tests do not adequately simulate dynamic loading effects, nor do they adequately assess damage at a stress level simulative of traffic loading, nor do they consider accumulated strain i.e., rutting.

AASHTO T-283 is an example of a monotonic loading test. In this indirect tensile test, tensile strengths before and after moisture conditioning are measured. The result is expressed as the ratio of the tensile strength of the moisture-conditioned material to the tensile strength of the untreated material. However, in AASHTO T-283 accumulated damage is not assessed. Furthermore, the test cannot be used to quantify reductions in the level or rate of damage. Lastly, the test is not an indicator of high temperature mixture rheology.

Resilient modulus testing (ASTM D 4123) can be used in conjunction with AASHTO T-283 to assess the damaging effects of moisture. The D 4123 procedures, however, determine resilient moduli at a stress state that is considerably lower than that which induces significant damage, and the number of load applications is limited.

An improved testing protocol to evaluate high temperature mixture rheology and the long-term effects of moisture damage must: (1) simulate dynamic traffic loading in terms of stress level and the cyclic nature of the loading, and (2) provide a result that can be quantified and used in a mechanistic-empirical models, such as those that will be in the AASHTO 2002 Pavement Design Guide The following protocol meets these requirements using: (1) repeated load triaxial mixture testing and (2) mastic fatigue testing. This protocol is summarized below, and discussed in more detail in Little [Volume 2].

A MORE REALISTIC CYCLIC LOADING TEST TO SIMULATE DAMAGE

Background

Repeated load triaxial testing has been used extensively to assess the resistance of asphalt mixtures to damage. This approach is attractive because it simulates the repeated loading action of traffic. The triaxial cell provides a confinement similar to that developed in the pavement, and the repeated axial load is applied in a manner that mimics moving traffic in terms of duration and of the load amplitude.

The triaxial approach is attractive because it can be used as part of a mechanistic design system such as that which will form the basis for the 2002 AASHTO Pavement Design Guide. In fact, the first step in the development of a mechanistic pavement analysis and design procedure began with National Cooperative Highway Research Program (NCHRP) Project 1-26, “Calibrated Mechanistic Structural Analysis Procedures for Pavements.” NCHRP 1-26 can be considered the forerunner of AASHTO 2002 as it established working models for the performance of materials to be used in pavement systems. To evaluate rutting and permanent deformation of the hot mix asphalt (HMA) surface, a repeated load triaxial test was selected to characterize susceptibility to rutting.

The Tseng and Lytton Model

The Tseng and Lytton model [1989] is a logical selection for the analysis of the accumulation of damage that occurs under repeated compressive loads in asphalt mixtures at high temperatures. The model is based on the assumption that as load cycling continues, a well-designed mixture will resist the accumulation of damage by strain hardening. If a mixture does not possess either the aggregate matrix or the characteristics of mastic rheology to resist damage, the arithmetic plot of accumulated strain versus number of load applications will separate from a hyperbolic plot where the strain becomes asymptotic. This separation visually demonstrates the ever-increasing accumulated strain with loading cycles—see Figure 5, page 4. A more sensitive graphical analysis is provided when one plots the linear rate of change of strain per cycle. A strain-hardening mixture produces a line with a strong negative slope, whereas a damage-susceptible mixture deviates from the negatively sloped line with an upward U-turn—see Figure 6, page 4. This approach is sensitive to mixture properties, including mastic high temperature rheology. Furthermore, mixtures that are more resistant at high temperatures produce more steeply negative sloped plots.

RECOMMENDATION FOR A SIMPLE MASTIC FATIGUE TEST

Smith and Hesp [1999] used repeated torsional fracture fatigue testing to evaluate the mastic. They found that fines have a substantial effect on fatigue due to crack pinning and energy dissipation and they concluded that smaller particle size distributions lead to increased fatigue life.

The torsional, controlled-strain fatigue test can be efficiently used to evaluate the influence of various volumetric concentrations of additives in bitumen. It is performed in a dynamic rheometer (Rheometrics RDA II or equivalent) using a rectangular torsion test fixture. The test is run in the constant strain mode. Fatigue damage is measured in the experiment as a reduction in stiffness of the mastic. Fatigue life in such experiments is typically defined as the value of dynamic shear modulus, G*, at which a 50% reduction occurs. Specimens are mounted in the rheometer, cooled until they reach an equilibrium temperature and tested at 10°C and 40 Hz with applied strains of between 0.15% and 0.6%.

CONCLUSION

Hydrated lime is a multifunctional additive that improves asphalt performance in many ways – by improving resistance to deformation and fatigue, moisture damage, aging, and low-temperature cracking. Lime has historically been viewed only as a modifier to reduce stripping, but the lab and field research summarized above demonstrates that lime’s benefits are much broader.

Repeated triaxial, torsional fatigue tests should be used to enhance HMA design and testing. These tests simulate actual traffic conditions and will better simulate long-term performance to facilitate mechanistic/empirical pavement design.

Highway designers should reconsider the use of lime and enhanced test protocols that will improve and extend pavement performance.

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The information provided in the article was obtained mainly from reports by Dr Dallas Little and Professor Jon Epps. For copies, please go to the publications area of our website, www.lime.org, or contact us at:

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