Association of Modified Asphalt Producers

AMAP White Paper Series

Moisture Damage in Asphalt Pavements

Contents

Executive Summary

Moisture damage in asphalt pavements is a critical distress that could lead to serious economic and safety consequences to the agencies and the users of the pavement respectively. This type of damage is considered a complex phenomenon manifested by a variety of extrinsic and intrinsic factors, including but not limited to poor pavement drainage, aged pavement materials, weather, etc. No matter the cause, at the fundamental level, moisture damage is the loss of strength and durability of asphalt mixtures is a result of loss of adhesive bond between asphalt binder and the aggregate surface and/ or the loss of cohesive resistance within the asphalt binder due to water (Kiggundu and Roberts, 1988). Agencies typically combat this expensive distress through the use of adhesion promoters. This paper discusses the various mechanisms by which asphalt-aggregate interactions are impacted by the presence of water and how various commercially available chemistries of adhesion promoters aid in improving the adhesion between them.

The paper also discusses the practical aspects of usage of adhesion promoters such as how these materials are supplied to the end users, where the adhesion promoters are introduced in the asphalt mixtures, and the implications of the point of introduction. The paper also dives into how agencies vet and accept the use of adhesion promoters and what this process means to the suppliers of adhesion promoters in terms of time and resources investment in the target geographies until a potential sale could be made. Understanding these aspects could help a potential supplier to make the decision to enter the market prior to devoting any efforts toward research and development or attempting the sale of the products in each market. Lastly, the paper talks about the possible reasons why differences exist in practice between results produced in laboratory environments versus field performance when evaluating an adhesion promoter.

Introduction

Moisture damage can be defined as "the progressive functional deterioration of a pavement mixture by loss of the ***adhesive bond*** between the asphalt cement and the aggregate surface and/or loss of the ***cohesive resistance*** within the asphalt cement, principally from the action of water" (Kiggundu and Roberts (1988)). Depending on the mechanism and extent, moisture damage in asphalt pavements can manifest as stripping, raveling, and potholes (shown in Figure 1).

Stripping – Defined as loss of bond between asphalt binder and the aggregate, stripping usually starts at the bottom of the hot mix asphalt (HMA) layer, and typically occurs due to poor pavement drainage that results in significant or sustained presence of moisture in the pavement.

Raveling – Raveling is similar to stripping, except that the progression of the loss of bond between the asphalt binder and the aggregate starts from the surface to the bottom of the HMA layer.

Potholes – Potholes are eventual manifestations of fatigue cracking in the asphalt pavements. As fatigue cracking severity progresses, the presence of moisture exacerbates interconnection of cracks causing small chunks of pavement to detach from the surface resulting in potholes.

Figure 1. (Top-left) Stripping (Halim and Ramani, 2016), (top-right) raveling (RoadBotics.com), and (bottom) potholes (Williams and Breakah, 2010) in asphalt pavements

While moisture damage is quite complex and not fully understood, the presence of such damage eventually leads to failures during the intended design service life of the pavement and hence, is a huge economic loss to society. Therefore, understanding and minimizing this distress is important.

How Does Moisture Damage Occur?

The complex phenomenon of moisture damage is not fully explained by one cause or mechanism but can be understood as a culmination of physical, chemical, thermodynamic, and mechanical processes that may occur simultaneously at varying rates. Some of the hypothesized mechanisms include detachment, displacement, spontaneous emulsification, film rupture, pore pressure, and hydraulic scouring, none of which are fully accepted (Kiggundu and Roberts (1988)).

Although presence of moisture is essential for the damage to occur, the processes mentioned above collectively contribute to moisture damage due to the presence of a combination of (Silvia, 2009)

- *External* factors such as weather (freeze-thaw cycles), trapped moisture at the time of construction, traffic (accelerated moisture damage due to load related distresses), etc.,
- *System attributes* such as aggregate properties, asphalt-aggregate interactions (adhesion), asphalt-asphalt interactions (cohesion), air voids etc.
- *Moisture transmission* induced by water diffusion and infiltration, capillary rise, etc.

Aggregate chemistry also impacts the stripping potential of asphalt mixtures (Figure 2). When moisture enters the asphalt-aggregate interface, the acidic groups in the asphalt binder react with water resulting in negatively charged compounds. Acidic aggregates, such as those rich in silica content, have negatively charged surfaces which repel the negatively charged compounds (in asphalt binder) in the presence of moisture, exhibiting higher stripping potential. On the contrary, basic aggregates that are rich in calcium content tend to exhibit lower or minimal stripping potential due to the natural attraction between the positive charge present on the aggregates and the negatively charged compounds in the asphalt binder.

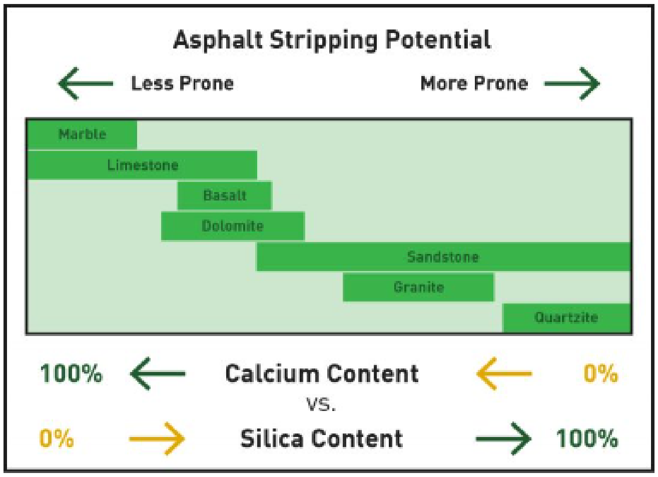
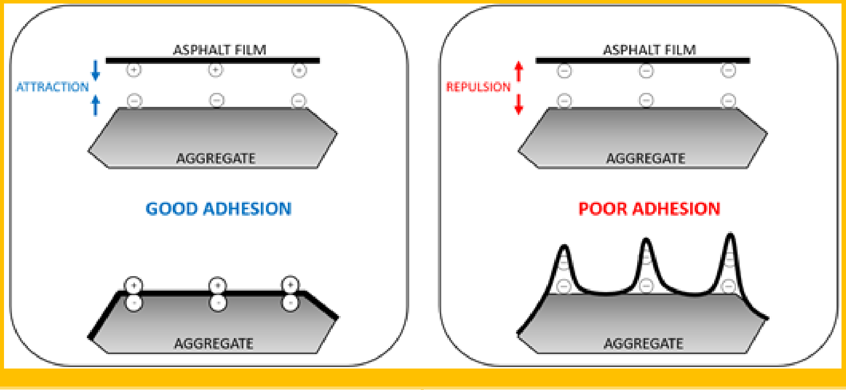


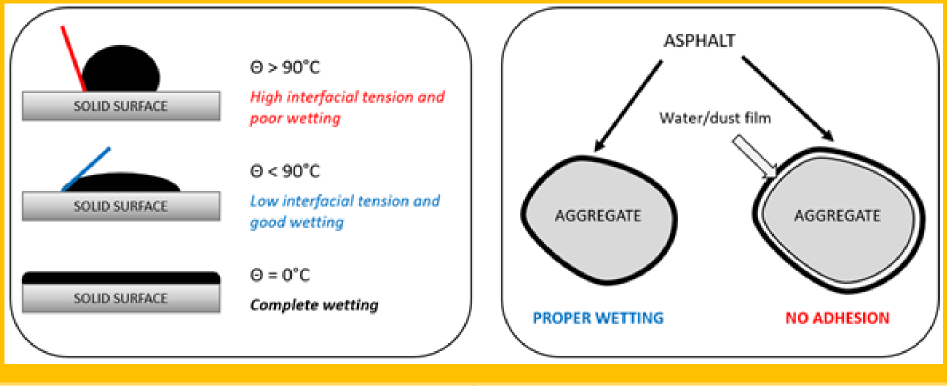
Figure 2. Impact of aggregate chemistry on the stripping potential (Credit: Mintek Resources)

To further understand the progression of moisture damage in asphalt mixtures, differences in asphalt-aggregate interaction with and without water are summarized in Table 1.

Table 1. Differences in asphalt-aggregate interaction with and without water

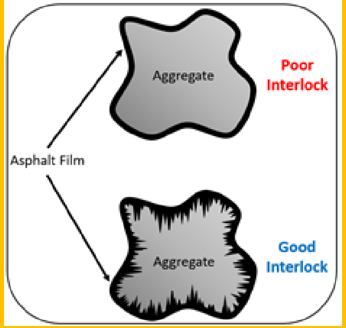
<table>
<tr><th colspan="2">MOLECULAR ORIENTATION AND CHEMICAL REACTIONS
 </th></tr>
<tr><th>When Water is NOT Present</th><th>When Water is Present</th></tr>
<tr><td>When asphalt binder comes into contact with aggregate surface, the orientation of asphalt molecules depends on the surface chemistry of the aggregate. If the asphalt binder and the aggregate surface have opposite charges, electrostatic bonds are created at the asphalt-aggregate interface, promoting attraction between the two resulting in good adhesion. In case of like charges, repulsion forces are generated causing the asphalt film to improperly adhere to the surface of the aggregate yielding poor adhesion.
Chemical bonding between the two materials also promotes adhesion. Polar asphalt molecules bind to polar surface aggregate molecules through hydrogen bonding and dipole-dipole interactions. Non-polar asphalt molecules bind to non-polar aggregate surface molecules through London dispersion forces.</td><td>In the presence of water, chemical bonding and electrostatic forces between the asphalt binder and aggregate can be disrupted. Aggregates have a higher affinity for water than for asphalt binder, which allows the water to easily displace and enter the space between the aggregate and asphalt binder impacting the interactions between the polar components of the aggregates and asphalt binder. This interaction also creates a barrier between the two because water molecules can form thin films around particles of aggregate, preventing adhesion between them.
Regarding siliceous aggregate, polar silanol groups are present on the aggregate surface and hydrogen ions are liberated in the presence of water, which results in a negatively charged surface. Similarly, the polar groups in asphalt at the asphalt-aggregate interface react with the water molecules making the binder negatively charged. The binder and aggregate surfaces are now both negatively charged, and that causes a repulsion between the two that results in poor adhesion.</td></tr>
</table>

INTERFACIAL TENSION



When Water is NOT Present	When Water is Present
Interfacial tension is the force per unit length that exists at the interface between one phase and another. In this case, the two phases are asphalt and aggregate. The wetting power of an asphalt binder depends on the other liquids present. When a liquid wets a solid surface, its tendency to spread out and form a large contact area with the solid indicates (contact angle < 90°) implies that the cohesive forces within the liquid are weaker than the adhesive forces and that the interfacial tension is low. If a liquid has low wetting power, the contact angle is greater than 90° as the liquid molecules form a droplet and resist spreading. Adhesive forces between the liquid and solid are lower, so the interfacial tension is higher between the two materials. Regarding asphalt-aggregate interactions, a high interfacial tension between binder and aggregate results in a weak adhesive bond because the binder does effectively wet the aggregate surface. Strong adhesive bonds arise when interfacial tension is low, which means the asphalt adequately wets the aggregate surface.	The polarity of water affects the interfacial tension between asphalt binder and aggregate. Water can interact with the polar components in both the asphalt and aggregate, which can affect the binder's ability to wet the aggregate surface. The adhesion tension is higher for water to aggregate than for asphalt to aggregate, so when all three are in contact, water has a tendency to displace the binder to form a more thermodynamically stable condition. Water can interfere with adhesion at the asphalt-aggregate interface by forming a thin film of molecules around the aggregate particles to create a barrier between the two. This increases the interfacial tension between asphalt and aggregate to weaken the ability of the binder to adhere to the surface of the aggregate.

MECHANICAL INTERLOCK



When Water is NOT Present	When Water is Present
Mechanical interlock is the physical mechanism between asphalt and aggregate in which binder hardens into the pores and along the surface irregularities of the aggregate surface. Angular and coarse aggregate have better adhesion stemming from better resistance to separation due to shear forces and more favorable surface for binder to stick. As binder penetrates the voids and crevices on the aggregate surface, network is formed within these voids which, when cooled, lock into the aggregate..	As water fills the voids between the aggregate particles, the mechanical interlock between the aggregate and binder is weakened. The reduction in available surface area for the asphalt to adhere limits the amount of contact points between the aggregate and binder making interlock more difficult. Water can penetrate into the asphalt and weaken its ability to coat the aggregate surface, which reduces adhesive properties of the binder. Fine aggregates are loosened as they become saturated with water, reducing the mechanical interlock. In certain types of aggregate, water can promote swelling of clay particles and reduce bond strength.

Furthermore, the presence of moisture could not only induce *new* damage to the pavements but may also further exacerbate existing distresses in the pavements (Varveri, 2015). In time, moisture-induced damage manifests either as adhesive or cohesive failure as demonstrated in Figure 3 (Wang et al., 2022).

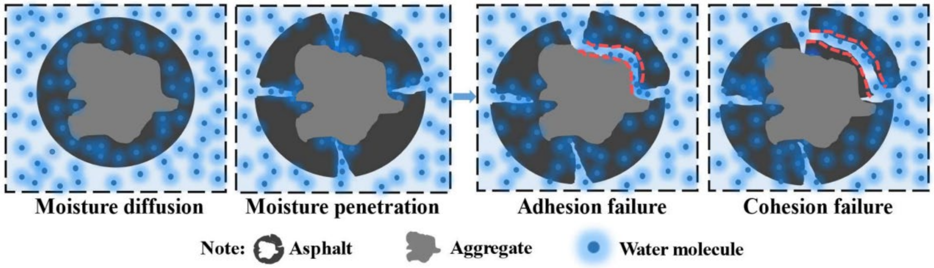


Figure 3. Schematics demonstrating moisture damage in asphalt pavements due to adhesive and cohesive failures.

Per the definition of stripping, which occurs due to prolonged presence moisture in the pavement as a result of poor drainage, the expected type of failure is predominantly due to adhesion loss i.e., loss of bond between the aggregate and asphalt binder. However, raveling on the other hand originates at the surface and progresses toward the bottom of the pavement layer. This is possibly due to the presence of aged asphalt binder near the surface due to direct exposure to elements resulting in a stiffer binder. This stiffness in the binder on the surface could be more prone to cohesive failure.

How to Prevent Moisture Damage in Asphalt Pavements?

The adhesion between asphalt binder and aggregate can be improved by using various adhesion promoter chemistries, or more commonly known as anti-strip additives (ASA). Adhesion promoters incorporate functional additives to strengthen the chemical bond between asphalt and aggregate.

Currently, the ASAs available in the market predominantly belong to one of the four categories below (defined in Table 2). The mechanisms of adhesion promotion are described in Table 3.

- Amines
- Phosphate esters
- Silane coupling agents
- Hydrated lime

Table 2. Types of ani-strip additives (ASAs) available in the market

TYPES OF ADHESION PROMOTERS			
Amines	**Phosphate Esters**	**Silane Coupling Agents**	**Hydrated Lime**
Amines are organic compounds derived from ammonia that contain a basic nitrogen atom and a lone pair of electrons. Functionality depends on the substituents attached to the nitrogen atom. Various types of amines that are used as liquid anti-strips are as follows: • Fatty amines • Polyamines • Amidoamines • Ethylene amines	Phosphate esters are active anionic surfactants with a central phosphate group, and their chemical properties vary depending on their functional groups. These materials are excellent hydrotropes and thus, can solubilize hydrophobic compounds in aqueous solutions. These additives are also compatible with polyphosphoric acid (PPA) modified binders.	Organosilicon compounds contain a silicon atom bonded to hydrogen, carbon or other organic functional groups. Silanes are the most common organosilicon. Silicon is tetravalent, so can form up to four chemical bonds, and the degree of substitution determines how the silane functions. These compounds typically have functional groups that can bond with both organic and inorganic materials.	Calcium hydroxide, or hydrated lime, is an inorganic compound coming from the product of calcium oxide and water. This material is a white, powdery substance with a slightly alkaline pH. Hydrated lime can be used as a mineral filler to increase the stiffness of the mix and as an adhesion promotor by reducing moisture sensitivity.

With the exception of hydrated lime, the remaining ASAs are liquid in nature, typically added at 0.25 to 0.75% by weight of asphalt binder. Note that when recycled asphalt pavement (RAP) is present in the mixtures, careful consideration is to be given if the prescribed dosage by the supplier is a percent of virgin binder or total binder (virgin + RAP binder). Hydrated lime is usually added as a dry powder to damp aggregate or as a slurry, typically at 1% by weight of the total mix.

Table 3. The mechanisms of adhesion promotion by various types of ASAs

MECHANISMS OF ADHESION PROMOTION			
Amines	**Phosphate Esters**	**Silane Coupling Agents**	**Hydrated Lime**
Amines can promote adhesion through chemical bonding. Reactions occur with carboxylic acid functional groups in asphalt to form strong amide linkages and, react with the silica in aggregate. Head groups of the amine will bind strongly to the aggregate surface and the hydrocarbon tails anchor themselves in the binder. The amine acts as a bridge between the binder and aggregate surface to displace water at the interface. Another mechanism is that the lone pair electrons react with silica to enhance adhesion by capturing protons from acidic groups in the polar components of asphalt creating a favorable surface for the binder to adhere. The lone pair forms hydrogen bonds with polar functional groups in the binder or on the aggregate surface to increase intermolecular forces. Amines can also work to reduce the interfacial tension by allowing the binder to better wet the aggregate. Creation of polar sites on the asphalt surface to promote adhesion between asphalt and aggregate, which improves the wetting ability of the asphalt.	Phosphate esters have polar functional groups that can form hydrogen bonds with the hydroxyl groups on the aggregate surface. These materials can also form bonds with the binder's oxygen containing functional groups to create another bridging effect. Phosphate esters work to alter the surface chemistry of the asphalt and aggregate to support a strong bond and resist water displacement. As a surfactant, phosphate esters reduce the interfacial tension between the asphalt and aggregate, which improves the wettability of the aggregate by reducing the contact angle between the binder and the surface of the aggregate. This promotes better contact and coating of the asphalt over the aggregate and produces a more uniform film. Better aggregate coating will also improve the mechanical interlock between the asphalt and aggregate.	Silane coupling agents are typically functional at both ends of the molecule, and hence, can interact with both the binder and the aggregate. One end reacts with the hydroxyl group of the silica particles in the aggregate, and the other end reacts with the organic functional groups of the binder to create a bridge between the two materials. Once that bridging effect occurs, the silanol groups on the aggregate surface now have a stronger affinity for the polar functional groups in the asphalt more than for the binder to create a stronger chemical bond and displace water at the interface. Organosilanes are tensioactive materials that change the surface tension between asphalt and aggregate. The binder's surface properties are modified, and there is an enhanced chemical attraction between the asphalt and aggregate. The reduction in tension improves the binder's wetting power, so the aggregate is better coated to promote adhesion and improve the interlock.	Hydrated lime has a strong affinity for water. In the presence of water, hydrated lime dissociates into calcium and hydroxide ions, which now can interact with asphalt molecules. Both types of ions absorb onto the binder's surface and are attracted to functional groups like carbonyls to promote a favorable electrostatic surface to improve adhesion. Hydrated lime can also form water-insoluble calcium salts with polar groups in asphalt, so silicon molecules in aggregate can bond with the nitrogen groups in asphalt, and these bonds promote adhesion. Interfacial tension can also be reduced with the addition of hydrated lime. The surface chemistry of asphalt is changed in the presence of lime to improve compatibility with water, improving the wetting power of the binder to reduce the interfacial tension between asphalt and aggregate to enhance adhesion forces.

Where are Adhesion Promoters Introduced?

Depending on the agency, adhesion promoters are either added at the terminal, to the Performance Grade (PG) binders, or at a hot mix plant through in-line injection by the contractor. While the point of introduction has various implications in terms of product approvals and so on, one of the critical considerations would be the way the asphalt mixtures are designed and approved.

When an adhesion promoter is blended at the terminal, typically, mix designers do not account for the portion of the binder that constitutes the adhesion promoter. The whole blend is considered as the binder itself i.e., the additive not treated as a separate mix entity, and the mix designs are created as such, if the additive is approved by the agency. In the case of in-line addition, the mix designers would be blending the additive during the design process. This would result in treating the additive as an individual component and hence, the mix ratios could be slightly different. Therefore, from a practical standpoint, the point of introduction has an impact on the mix design process. This could have an implication on the actual amount of asphalt binder that needs to be added to the asphalt mixture and hence, the cost of the mix and eventually, the performance itself.

Another key consideration during terminal or plant introduction is the dosage monitoring. Use of appropriate systems, such as calibrated mass flow meters or scales to track the amount of ASAs added during production, is important. ASA monitoring could be included in the quality control (QC) program of the terminal/ hot mix asphalt plants. In addition, to reduce errors at the time of introduction, charts to guide dosage based on binder content or mix tonnage could be developed and posted in the production control rooms to guide the plant operators. Ultimately, the goal of dosage monitoring, QC programs, and the dosage charts is to achieve proper dosage.

How are Adhesion Promoters Typically Supplied?

Dry addition or powder additives are typically supplied in 50-lb bags (or other weights) while liquid or wet addition additives are typically supplied in totes that typically have capacities of 275 or 330 gallons (Figure 4). If corrosive or flammable in nature, special storage conditions are to be maintained and utilized for safe handling and operation at hot mix asphalt plants or terminals.

Figure 4. Totes and bags are typically used to supply liquid and powder antistrip additives

How are Adhesion Promoters Vetted by Agencies?

State/Agency Approvals

Any additive that is intended to be a part of a road maintained by an agency is subject to an approval process to be entered into their qualified products lists (QPLs) or approved products list (APLs). Usually, the approval process can be long and time consuming, as every agency has their own testing program (with local aggregate sources and a vetting test trusted by them) possibly combined with a field project. Although every agency has their methods to test ASAs, the three major tests that are typically used are described as below and are shown in Figure 5.

Modified Lottman or Tensile Strength Ratio (TSR) Test (AASHTO T 283):

Overview: TSR test is a popular moisture damage evaluation test utilized by the agencies to vet and approve ASAs. The test method utilizes asphalt mix prepared with ASA under consideration with aggregate and binder sources, usually known to exhibit (and not exhibit) stripping issues. In its essence, three mix specimens are conditioned through partial vacuum saturation with water (and a defined freeze-thaw conditioning step, depending on the agency) and three specimens are left unconditioned, i.e., mixed and compacted. Note that some agencies require the conditioned specimens to be subject to three freeze-thaw cycles while some may require up to six freeze-thaw cycles, especially in alpine regions, causing this test to be time and labor intensive.

The specimens are then tested for their split tensile strength. The TSR ratio, defined as the ratio of tensile strength of conditioned specimens to that of unconditioned specimens, is determined and compared to the minimum specification value set by the agency. Most agencies require a minimum TSR ratio of 0.80 when an ASA is used, implying that whenever the mix under consideration is subject to conditions that supposedly cause moisture damage, the tensile strength of the mix should not reduce by more than 80% of the unconditioned (or undamaged) mix. This limit is imposed because asphalt mixtures tend to exhibit cracking when the tensile stresses reach and go above their tensile strength; and under moisture damage, the tensile strength of the mix is reduced. Sometimes, a minimum specification value on the tensile strength of the unconditioned mix is also imposed by the agencies.

Practical Considerations: Although widely used, TSR test in practice is known to exhibit high variability (poor precision and bias) and opposing results in the lab vs. field. Practitioners have reported seeing passing TSR values in one lab and failing values in another for a given mix design, as well as mixtures with passing TSR values in the lab exhibiting moisture damage in the field and vice versa. Several reasons could cause this variability and discrepancy in mix performance including difference in the interconnected air voids (air void structure) between specimens which could cause varying levels of moisture damage during freeze-thaw cycles and possibly, the mix conditioning not being representative of the way moisture damage is induced in the field. Other possible causes are discussed in the latter section of the paper.

Boil Test (ASTM D3625):

Overview: Boil test requires loose mix prepared with ASA to be added to boiling water and subjectively determine of the extent of visual moisture damage as compared to the same mix that was not subject to boiling. In this test, moisture damage is identified as the loss of asphalt binder coating around the aggregate.

Practical Considerations: Although simple to perform, the boil test is subjective, and the testing conditions are too severe and non-representative.

Hamburg Wheel-Tracking (HWT) Test (AASHTO T 324)

Overview: HWT test is typically performed on mix specimens submerged in water at a temperature higher than ambient. The specimens are subject to wheel loading that track across the samples for the number of cycles as set by the agency. Rut depth of the specimen is tracked throughout the test and moisture damage, if induced, is seen through stripping inflection point where stripping begins and results in higher rate of rutting.

Practical Considerations: Sometimes, a hardener which necessarily may not improve the adhesion characteristics of the mix could give a false positive during the test and could cause them to pass the specifications set by the agency.

Figure 5. Tests typically used for vetting ASAs by agencies: (left) tensile strength ratio (TSR) test (Pavement Interactive), (center) boil test (Yadav et. al (2022), and (right) Hamburg wheel tracking (HWT) test (Pavement Interactive)

AASHTO Product Evaluation & Audit Solutions

Another way to get the ASAs vetted for consideration of approval by agencies is through AASHTO Product Evaluation & Audit Solutions, previously known as the NTPEP (National Transportation Product Evaluation Program) program. This program, run by AASTHO, is aimed at reducing the duplication of efforts by the state DOTs during the product evaluation and approval process by allowing the manufacturers and suppliers to submit their products for independent testing, which could be used by the AASHTO members to make their product approval decisions. Per the NTPEP program, ASAs are evaluated for the following properties:

- Fourier Transform Infrared Spectroscopy (FTIR) on the ASA
- PG Grade Determination per AASTHO M 320 and MSCR (AASHTO T 350) on the binder blend made with a neat PG 64-22 and ASA
- Mix Design Verification (AASHTO R 35), Hamburg Wheel Tracking Test (AASHTO T 324), Tensile Strength Ratio Test (AASHTO T 283), and Boil Test (ASTM D3625) on mixture made with PG 64-22 + ASA blend.

Test results on the products evaluated so far can be found on NTPEP database. Participating state agencies may choose to use the testing data produced as part of NTPEP but apply their own specification limits on these results. For instance, Ohio DOT utilizes NTPEP data but has their own rules on approving the ASAs.

Critical Considerations for Adhesion Promoter Suppliers

Specifications are the bread and butter of asphalt industry. When critically mapped out, the livelihood of every stakeholder/worker in this industry is dependent on a material or job being supplied or built to an agreed upon specification as enforced by the owner agencies. Due to this, a company/supplier selling a modifier in the asphalt industry must understand the specification terrain for that modifier and the target geography at the use location.

Although blanket specifications are available for certain products at national (AASHTO) and possibly at international level (ASTM), each owner agency usually adopts or customizes the specification based on their performance history, materials available, history of tests utilized etc. For instance, although AASHTO M320/M332 is the PG binder specification for asphalt binders utilized in the hot asphalt mixtures, every state agency specification book usually uses a portion of the M320/M332 specification or adds to their adopted version. This aspect of specification customization by agencies has a serious impact on the material suppliers because specifications are the key to their products being eligible to be considered or placed in a state's APL.

The path for a modifier to enter the APL is dependent on the modifier type but could generally be outlined as shown in Figure 6. Suppliers must study the individual agency specification books and possibly contact the respective state materials offices to understand the process involved – even prior to considering a research and development (R&D) effort to develop modifiers, primarily due to the amount of time, resources, and the effort needed prior to a sale. Spending the time doing this exercise is essential to determine if market entry is worthwhile.

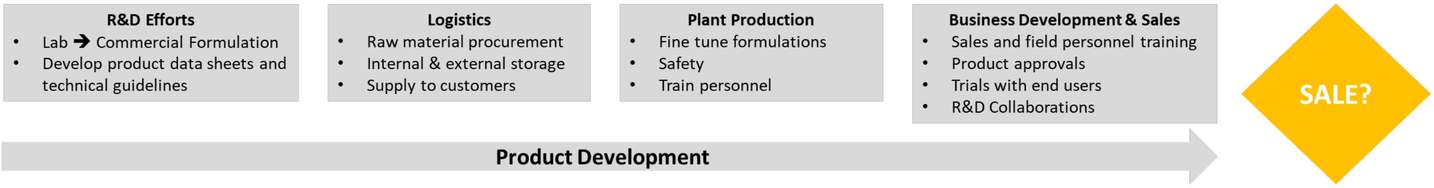


Figure 6. Typical product development process toward a possible sale in the asphalt market

Once a product is ready for sale, going through the product approval process in the target geographies is a major bottleneck. The supplier is required to submit their product in an appropriate manner as outlined by the owner agencies for vetting through their approval process. Once successful, the agency would add the product to their APL which *allows* the material suppliers and paving contractors to use the product. Once the product is listed in the APL, developing relationships with contractors and other partners to use their product is the next step for the suppliers.

Practical Considerations Toward Utilizing Adhesion Promoters

As previously mentioned, some agencies have experienced stripping in their asphalt pavements despite measuring passing TSR values on lab fabricated mixture specimens produced per the job mix formula (JMF) i.e., the mix design approved to produce the asphalt mixture. Some potential causes for these are rare but possible ones could be:

- **ASA Dosage Prescription & Mobilization of RAP Binder:**
  The typical antistrip dosage is often calculated based only on the weight of the virgin binder, and hence, may not always consider the weight of the recycled binder if RAP is present in the mix. This phenomenon can become exacerbated when a mix contains higher RAP percentages, which would reduce the amount of virgin binder in the mix and hence, the amount of ASA as well. Further

complicating this issue is RAP binder mobilization. It is likely that not all the RAP binder becomes mobilized during mix production and compaction and yet, RAP is most often credited for contributing 100% of its binder fraction to the mix, resulting in under asphalted mixes. As expected, this issue is more pronounced in high RAP mixes, which could result in stripping and poor mixture performance in the field. Even if "extra" antistrip were to be added to the virgin binder to compensate for the weight of the RAP binder in the mix, variability in RAP material itself could cause the discrepancy between lab and field performance of ASAs.

- **Differences between Lab and Plant Mixing:**
  Lab and hot mix asphalt (HMA) plant could yield very different mixtures for the same JMF. RAP only has seconds to be mixed in at a hot mix asphalt (HMA) plant, once introduced at the RAP collar. In a lab setting, the blending can be more thorough with longer mixing time which allows for greater release and incorporation of a higher amount of RAP binder into the mix. This could result in opposing mix performance in the lab vs. field i.e., good performance in the lab and bad performance in the field and vice versa .
- **Presence of PPA in RAP**
  Further research would be needed to determine if incompatibility issues would arise if amine based ASAs are used with a RAP source that may have been originally produced with PPA modified binders.

Conclusions

In conclusion, moisture damage is a serious pavement distress from a safety standpoint and an expensive one to the agencies that are responsible for maintaining them. However, through appropriate engineering of the mixture properties to improve the adhesion between the asphalt cement and the aggregate surface and the cohesive resistance within the asphalt cement, moisture damage in pavements can be minimized. There are various adhesion promoting chemistries that are available in the market today and their interaction mechanisms have been briefly discussed in this paper.

Further, practical aspects of utilizing adhesion promoters are also reviewed in this paper, including the methods of introduction of adhesion promoters, some of the processes or test methods utilized by agencies to approve and added ASAs to their APLs, and how potential ASA suppliers could be impacted by the differences in vetting products that are enforced by various owner agencies. Lastly, some of the experiences of practitioners with regard to performance of adhesion promoters in the light of increased use of RAP, its variability and composition, and the RAP binder mobilization are discussed.

Picture Credits/References:

- Caro Spinel, Silvia (2009). A Coupled Micromechanical Model of Moisture-Induced Damage in Asphalt Mixtures: Formulation and Applications. Doctoral dissertation, Texas A&M University. Available electronically from https : / /hdl .handle .net /1969 .1 /ETD -TAMU -2009 -12 -7336.
- http://all-county-paving.com/what-causes-asphalt-paving-to-deteriorate/
- Williams, R. Christopher and Breakah, Tamer M. (2010). Evaluation of hot mix asphalt moisture sensitivity using the Nottingham Asphalt test equipment : tech transfer summary, March 2010.
- https://www.roadbotics.com/2019/10/07/distress-call-raveling/
- Halim, A.A., & Ramani, M.V. (2016). Stripping Distress on Hot Mixed Asphalt Pavement.

- Wang, Wenqi & Nili, Azuo & Rahman, Ali & Chen, Xu. (2022). Effects of Wax Molecular Weight Distribution and Branching on Moisture Sensitivity of Asphalt Binders. Materials. 15. 4206. 10.3390/ma15124206.
- Transportation Research Board (Washington D.C.). (2003). Moisture sensitivity of asphalt pavements - a national seminar : 2003 : san diego calif. TRB.
- https://mintekresources.com/anti-stripping-agent-for-asphalt/
- www.pavementinteractive.com
- Yadav, S., Kusam, A., Tayebali, Z.M., Tayebali, A.A. (2022). Determining Optimum Antistripping Additive Content in Asphalt Mixtures Using Boil Test. In: Singh, D., Vanajakshi, L., Verma, A., Das, A. (eds) Proceedings of the Fifth International Conference of Transportation Research Group of India . Lecture Notes in Civil Engineering, vol 218. Springer, Singapore. https://doi.org/10.1007/978-981-16-9921-4_19
- This Photo by Unknown Author is licensed under CC BY