IntegraBase Technical Brief

RESPERION
Road Engineering Solutions

February 2007

TABLE OF CONTENTS

1. Resperion Overview

Resperion is a leading provider of asphalt paving solutions to governmental agencies and private organizations worldwide. Resperion develops, manufactures and markets various chemical modifiers used to improve specific properties of asphaltic concrete paving mixtures; namely, strength, temperature susceptibility and aggregate adhesion. Resperion manufactures the only modifier which so dramatically increases the structural capacity of asphaltic materials that it is possible to reduce the thickness of the base course and lower initial construction costs.

Founded in 1999, Resperion acquired patents and core technology that had been used in numerous highway and road projects worldwide for more than 20 years. Prior to 2004, the product was sold under the name Chemcrete. Resperion has since refined the technology, optimizing it for use in specific road building applications.

Headquartered near San Francisco, California, Resperion is led by an experienced management and engineering team focused on enabling road designers build stronger, longer lasting roads at a fraction of the cost of traditional materials. Resperion also has sales offices in Afghanistan, Malaysia, Mexico, and Poland.

Resperion Applications:

Road & Highway
Ports
International Aid Projects
Military
Private, Commercial & Home Development
Airports
Railroads

2. IntegraBase Chemical Reaction

Introduction
IntegraBase modifier is composed essentially of organo-metallic components dissolved in a softening oil. IntegraBase is a catalyst which, unlike polymer additives, reacts with bitumen and changes the chemistry and the molecular structure of the bitumen under the influence of temperature and oxygen.

This catalytical reaction results in the formation of ketones at the most reactive sites within the bitumen molecules, thereby greatly reducing the bitumen's susceptibility to oxidative ageing, and improving its anti-stripping properties. In a second consecutive phase, the organo-metallic components of the IntegraBase modifier will react with the ketones, producing strong, irreversible bonds between the bitumen molecules, resulting in a bitumen with highly reduced temperature susceptibility.

2.1 Chemistry of Conventional Bitumen

2.1.1 Chemical Structure
Bitumen is a very complex mixture of organic molecules which vary widely in composition from non-polar saturated hydrocarbons to highly-polar, highly-condensed aromatic ring systems. In all bitumens, a fundamental building block in this complex mixture of aromatic and aliphatic hydrocarbons is a structure called tetrahydronapthalene, or more commonly known as, tetralin.

From a structural point of view, tetralin can be thought of as a benzene ring and a cyclohexane ring fused together. These tetralin structures come together in many various patterns in which the aromatic components form two-dimensional arrays or platelets. These platelets will arrange themselves in the stacks of layers whenever the bitumen solidifies.

These layers are bound only by the electrostatic forces inherent to hydrogen bonds – when the bitumen is subject to low temperatures, the platelets are strongly bound together, making the bitumen stiff; when the bitumen is heated, these bonds become very weak, and the platelets will slide apart, causing critical limitations on cohesive strength. Simply stated, the hydrogen bonds between the platelets in bitumen are the main reason for conventional bitumen to be highly susceptible to temperature change.

2.1.2 Aging of Conventional Bitumen
The reaction of bitumen with atmospheric oxygen is the major factor leading to the hardening and embrittlement of bitumen. The primary mode of oxygen uptake is at those carbons which are immediately adjacent to a benzene ring; they are the "benzyl carbons" and are far more reactive than any neighboring carbon atoms.

Atmospheric oxygen attacks the bitumen at these benzylic sites to form a hydroperoxide (fig. 1.1). Naturally the same oxygen uptake will occur at the upper and lower benzylic sites, so that two hydroperoxides will be formed on most tetralin molecules.

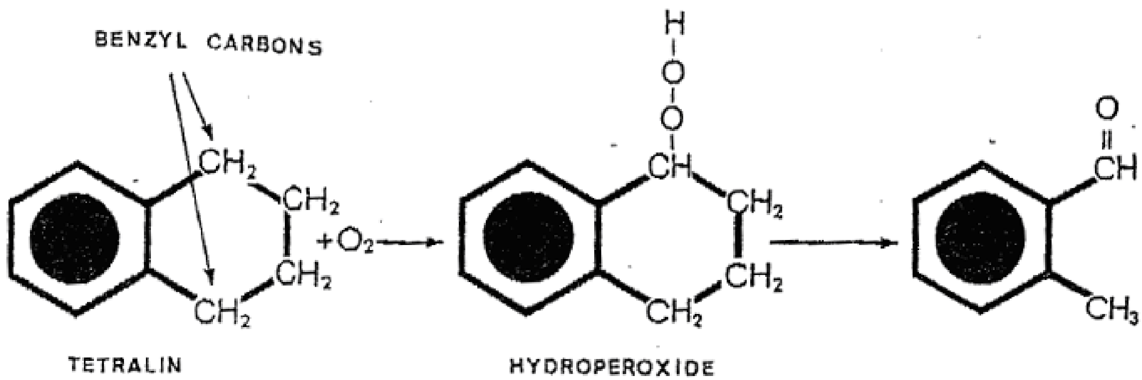


Fig. 1.1 – Example of destructive oxidation through hydroperoxide leading to a free radical chain reaction

The formation of these hydroperoxides is particularly detrimental in bitumen because the bond between the two oxygen atoms is inherently weak and will readily break to form a free radical, which in turn, may be the cause of:

a. Breaking of molecular carbon-to-carbon bonds in the napthenic ring of tetralin, hence, undermining the structural integrity of the bitumen
b. Catalyzing the uptake of more atmospheric oxygen to form even more unstable hydroperoxides.

This oxidation process illustrates the beginning of a chain reaction which is the cause of the classical oxidative degradation of bitumen.

2.2 IntegraBase Chemistry

The reaction between IntegraBase and bitumen is purely “thin film” chemistry (e.g. 0-30 microns.) Factors which affect the reaction of IntegraBase with bitumen are temperature, oxygen and time. Temperature accelerates the reaction (a doubling of speed with every increase of 10^0C.) If oxygen is not present, there will be no reaction – oxygen is the trigger in the reaction. However, the reaction is not standard oxidation, as oxygen becomes part of the final product – an organic-metallic compound. The time for reaction is fairly consistent for all asphalts – most of the reaction occurs in the first 30 minutes, then moves slowly from that point on. Once this reaction takes place, it can never be reversed.

IntegraBase modifier contains an organo-metallic manganese complex which, when mixed with bitumen, causes two separate and sequential chemical reactions, resulting in a permanent change of the chemistry and molecular composition of the bitumen.

In the first part of the reaction, the organo-metallic complex acts as a true catalyst forming predominantly ketones. In the second part of the reaction, the manganese crosslinks the bitumen platelets.

2.2.1 Formation of Ketones

In the first reaction, the organo-metallic manganese complex acts as a true catalyst, catalyzing the addition of oxygen to benzylic carbon groups, converting these benzylic carbon groups almost quantitatively to ketone groups. In the fundamental building block, tetralin, the initial reaction first forms the tetralin monoketone. But since both the benzylic sites are reactive, the catalytic reaction induced by the IntegraBase modifier subsequently forms diketones and hydroxyketones.

In this way the very stable ketones are formed, rather than other oxidation products, and the detrimental free radical chain reaction which otherwise leads to the rapid aging of conventional unmodified bitumen is broken.

Furthermore, most of the oxidizable sites of the bitumen have been converted to ketones, and ketones cannot be readily oxidized into breakdown products; for this reason, IntegraBase modified bitumen will age more slowly than unmodified bitumen, once the initial catalytic curing has stopped.

An additional positive characteristic is that ketones are very effective anti-stripping compounds in asphalt because their polarity gives them the ability to resist water displacement; since a great amount of ketones are formed, IntegraBase modifier is far less sensitive to water stripping than unmodified asphalt.

The formation of Ketones can be demonstrated by infrared spectroscopy. The ketones found in bitumen characteristically absorb light in the spectral region defined by wave numbers around 1690 cm^{-1}. The comparison of the relative levels of absorbance for conventional bitumen and IntegraBase modified bitumen in this spectral region confirms that a very significant amount of ketones is formed in the IntegraBase bitumen, while only a small amount of ketones is evident in the unmodified bitumen.

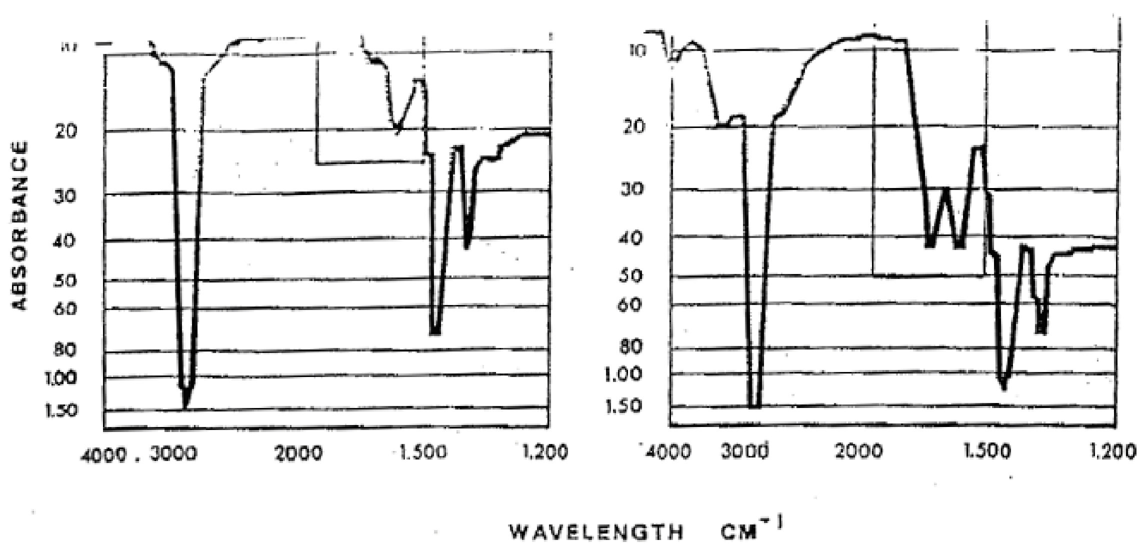


Fig. 1.2 – Infrared spectra of unmodified bitumen and IntegraBase modified bitumen. (recovered bitumen from test road)

2.2.2 Bitumen Cross-Linking

In the second reaction caused by the IntegraBase modifier, the manganese is irreversibly complexed with the diketones formed in the first reaction; the result is a link between the diketones on vertically adjacent molecules of bitumen platelets. It is interesting to note that the diketones and hydroketones have exactly the correct atomic spacing for the manganese to fit in between the platelets, which means that the complex formed with the manganese ion is very stable.

There is a rule in chemistry which states that metal complexes quickly transform into the most stable form possible, meaning that the manganese organo-metallic complex will quickly convert to the diketones-manganese complex once the diketones are available. These manganese-diketone complexes are very stable and involve interactions with the d-orbitals of the manganous ion. Therefore, the manganese is completely de-activated and will not act as a catalyst for further oxidation.

A view of the three-dimensional model (fig 1.8a) shows the way in which the manganese-ketone complex ties together vertically adjacent bitumen molecules.

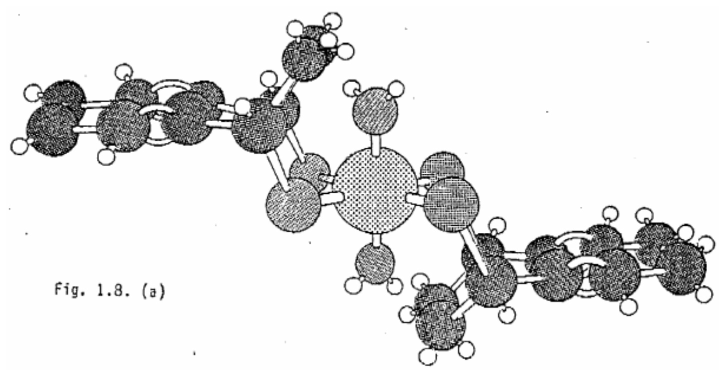


Fig. 1.8. (a)

This new, very strong bond makes the bitumen much stronger because some of the plate-like bitumen molecules are prevented from slipping with respect to each other. The cross-linking is easily visualized in an "edge-on" view, depicting the plate-like structure of the bitumen; they can be viewed as being like additional cross members or struts in a structure. In conventional bitumen, the platelets are only held together by electrostatic forces which are very weak at higher temperatures, causing the platelets to slide apart when under high stress at higher temperatures – resulting in asphalt's well-known lack of strength.

At higher temperatures in the IntegraBase modified bitumen, the cross-linking of the bitumen platelets gives the bitumen very high strength; on the other hand, at low temperatures, the bond between the platelets in conventional bitumen is sufficiently strong for the cross-linking not to give any additional strength to the bitumen. This results in IntegraBase modified bitumen being less temperature susceptible than the unmodified bitumen. The higher the temperature, the greater the difference in strength between the modified bitumen and the unmodified bitumen.

The formation of this manganese-ketone complex can be verified by noting the shift which occurs in the molecular weight distribution of IntegraBase bitumen when compared with unmodified bitumen. This is illustrated in fig 1.3; as would be expected, the crosslinked IntegraBase bitumen has an increased average molecular weight.

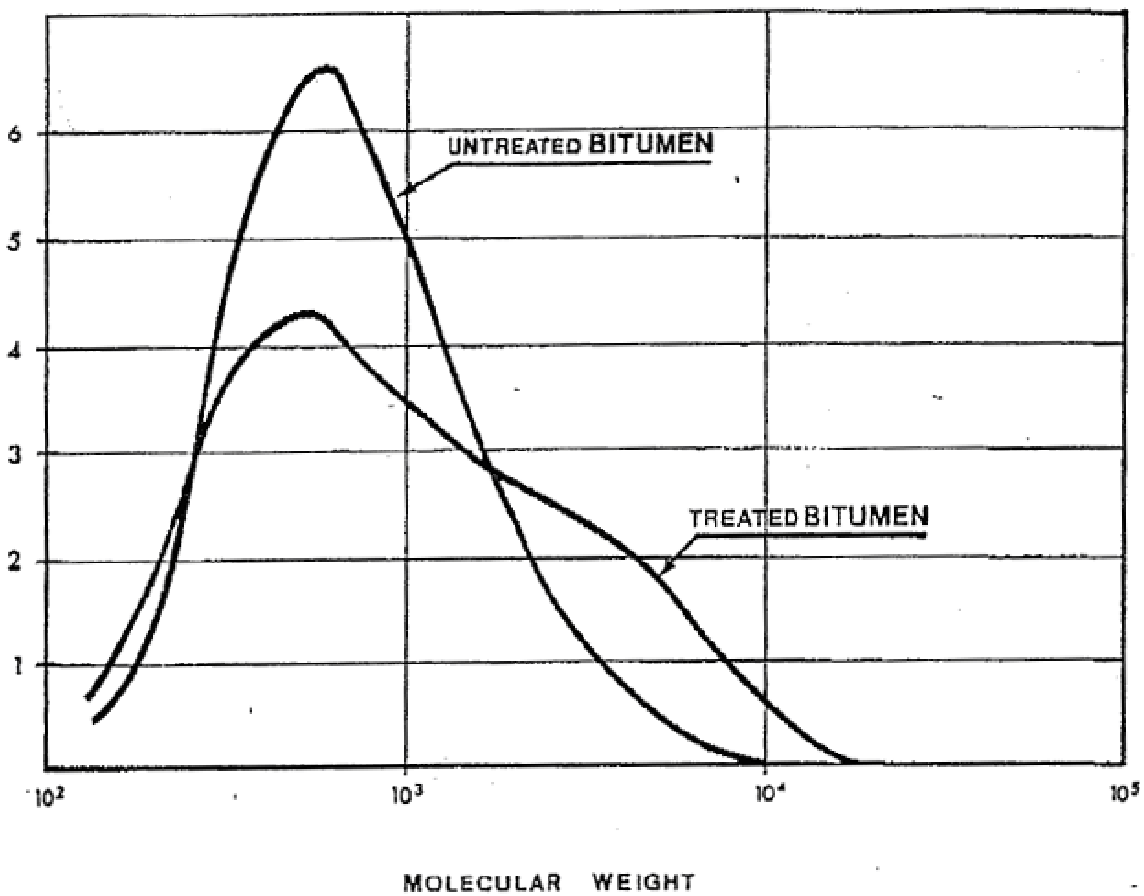
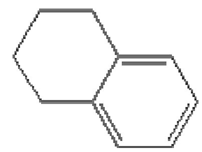


Fig. 1.3 – Molecular weight distribution of IntegraBase modified bitumen and unmodified bitumen by High Pressure Liquid Chromatography. Vertical axis represents relative absorbance in arbitrary units and horizontal axis molecular weight.

2.2.3 Reactions with Different Bitumens

The reaction of IntegraBase with different bitumens is fairly constant – the main difference being the quantity of catalyst required to drive the reaction. The apparent difference is the quantity of catalyst lost in other secondary reactions; this is the sole reason that it is recommended that at least 2% modifer by weight of bitumen be used. The variable which determines how reactive IntegraBase is with the asphalt is the percentage of tetralin structures contained in the asphalt. All asphalts have tetralin structures, but to varying quantities. The more tetralin in the asphalt, the better the reaction.



Tetralin Structure

Napthenic and aromatic asphalts tend to have the highest quantities of tetralin structures – These asphalts are commonly found in the middle east and Venezuela regions. China and Russia tend to have asphalts with the lowest percentage of tetralin structures.

2.2.4 Reactions with Different Aggregate Types

The IntegraBase modifier doesn't react with inorganic aggregates other than cement and quicklime (Calcium Oxide – CaO.) Soluble cobalt and iron salts do act as secondary catalysts, but are not serious primary catalysts. Listed are some aggregate types that are usually used with IntegraBase to ensure proper pavement performance:

- Igeneous rocks: Volcanic rocks formed from molten rock. Examples are granite and basalt.
- Sedimentary rocks: Rocks formed by the laying down of layers of material that is then compressed. Examples include: limestone, sandstone and chert.
- Gravel: Formed from the breakdown of any natural rock. Usually found in rivers or waterways. River-run gravel is an example.
- Sands: These are formed from the deterioration of any natural rock. These often contain clay or silt and should be washed.
- Slag: This is a by-product of metallurgical processing. Slags can be from tin, steel or copper processing. Slag is generally hard but absorbent.

3. IntegraBase Handling

3.1 Storage

Since the IntegraBase chemical reaction is a "thin-film" chemistry, there are no bulk storage limitations in terms of time or temperature. IntegraBase is a completely soluble product. Unlike polymers, IntegraBase never experiences settling of chemical constituents; this alleviates the need of having to mix the product before it is added to the bitumen. The implementation of IntegraBase doesn't require shear when mixing the modifier and asphalt. IntegraBase can be stored indefinitely, as there is no known shelf-life. Over time the IntegraBase modifier may form a thin skin on top, which is completely dissolvable with a little mixing or stirring. IntegraBase can be stored in any material including: plastic, rubber, metal, etc. – the product is non reactive, enabling a wide variety of storage options. IntegraBase can be frozen, freeze thawed for storage without any negative effects to the product.

3.2 Viscosity

The viscosity of IntegraBase @ 40^0C (ASTM D445) should be limited to 1000 centipoise so as to allow handling, mixing and pumping at most common temperatures. The viscosity of IntegraBase is completely based on the aromaticity of the oil in the product – therefore, decreases in temperature lead to increases in viscosity. The optimal product temperature at time of blending is approx 70^0- 80^0F. Pumps and weighing devices must be calibrated as the viscosity of IntegraBase may fluctuate with temperature changes. There are no other ways to alter the viscosity of IntegraBase other than temperature. Resperion recommends that whenever the product is going to be used in cold temperatures, that some type of heating device be used to keep the product at a low viscosity. More information about heating of the product can be found in section 6.4.

3.3 Safety

IntegraBase contains no harmful chemicals, and has no special handling requirements. All chemicals contained in IntegraBase are registered and approved for use by the EPA and OSHA. All information concerning safety can be found in the IntegraBase Material Safety Data Sheet (MSDS – appendix A.) In case of spills, it is recommended to add an emulsifier to IntegraBase, which will in turn, create an emulsion.

3.4 Transport Options

There are no transport restrictions when shipping IntegraBase. IntegraBase can be shipped by air, land and sea; there are many options for the actual storage of the product including, drums, totes, bladders, etc. Storage options are usually dependent on the size of the project – the smallest jobs can be served by 55-gallon drums while the largest projects are best served by rubberized bladders placed in 20-foot containers.

4. Lab Testing of IntegraBase

4.1 Procedures

The IntegraBase modifier is a series of chemical reactions, it is important to make sure that a proper mix of modifier and asphalt are prepared so that the reactions can be completed. A large batch, at least ten times the quantity that will be used in preparation of the test samples, should be prepared. Typically a sample of 16oz. of IntegraBase should be sufficient for a full battery of tests.

4.1.1 Step-by-Step Process

- Prepare the Chemcrete-modified binder: Blend the Chemcrete modifier at 2% by weight into the binder using a high shear blender (i.e. high Reynolds number). The blending should occur over a 5 minute period at a temperature of 120^{o}C.

- Prepare a laboratory mix using a standard aggregate source and a standard dense gradation with the Chemcrete-modified binder. Use an optimum binder content that has been determined as appropriate for the selected aggregate source and gradation.

- Place the loose mix in a laboratory tray and cure it in an oven for 30 minutes at 150^{o}C.

- After the first 30 minutes curing, gently remix the loose mix in the tray with a large laboratory spoon and cure it for an additional 30 minutes in the oven at 150^{o}C.

Extract and recover the binder from the mix using the centrifuge extraction process and the laboratory standard recovery process (i.e. the Apson and Rotovapor methods are both acceptable).

4.1.2 Additional Notes to Testing Process

The modifier should be put into the kettle first, followed by the addition of bitumen and blending. This can easily cut down on the blending time. Mixing is the most important step in the sample preparation process – “If they don’t meet, they don’t mate.” Since IntegraBase is a catalyst, it is imperative that it be well dispersed throughout the bitumen. If a lab doesn’t have a high shear blender, it is possible to use a simple household blender or the like. It is also important to follow the exposure time to oxygen – which can easily affect the outcome of the test.

4.2 Standard Lab Results

A doubling of resilient modulus can be expected at 104^{0}F, as well as a 50% increase in constant-stress fatigue. Better wet strength can be expected because of the improved adhesion properties. Low-temperature properties will not be adversely affected.

4.3 Lab Tests to Avoid

It is recommended that ductility tests be avoided because of the increased strength that IntegraBase introduces to the modified asphalt. Forced ductility is a better test for IntegraBase, as the measure of force is included in the test results. Tests that focus on slow rates of loading are the best tests to highlight the strengths of IntegraBase – the best test that exhibits a measure of strength with a slow rate of loading is Resilient Modulus. Marshall Stability tests have a faster rate of loading, which leads to less impressive results.

Many people are interested in testing IntegraBase using accelerated aging tests (RTFO) – as aging is a concern for some people. Since our product is a catalyst, it is unreasonable to test it in this fashion. Aging tests increase temperatures, which are an unrealistic measure of actual road conditions; tests of this nature will accelerate the action of our catalyst and will not produce results that would ever be found in actual implementations.

4.4 Specific Tests and Expectations*

Resilient Modulus

Expect a doubling at 40^{o}C at a lower rate of loading; a tripling is not out of the question.

Marshall Stability

Typically expect a 25-30% increase

Indirect Tensile Strength

Tensile strength at higher temps usually doubles

Wheel Tracking

40^{o}C, at least half of the rut depth of the control

Stripping

IntegraBase treated specimens always exhibit a higher wet strength. Stripping is an interesting test; as cores are soaked, IntegraBase samples tend to lose a higher percentage of strength after soaking, but looking at the results relatively, IntegraBase has a higher starting point, and still has a higher wet strength at the end of the test. Hydrophillic aggregates are attracted to water, and even with IntegraBase, need help from other products such as lime, etc.

** Please see Section 10 for actual IntegraBase test results*

5. Product Integration

5.1 Mix Properties
Extensive testing has shown that the optimal content of IntegraBase to add to bitumen is 2%. Adding more will only incrementally increase performance, however, economically, it just doesn't make sense. At least 90% of the reaction will be achieved from the 2%. There are some mixes that will work better with a lower percentage, but on average, it is always recommended to stick with 2%.

The IntegraBase modifier is intended to replace 2% of the total amount of bitumen added, as it contains many of the same beneficial characteristics of bitumen. However, it is possible to add the 2% IntegraBase in addition to the total percentage of bitumen.

The optimal binder content for an IntegraBase mix is exactly the same as it would be for an untreated mix. Void contents are the same as well, somewhere between 3-7% is optimal.

5.2 In-Line Dosing
While small variations in the dosage rate will not affect overall performance, optimal dosage is best achieved through the use of the Resperion Automatic Dosing Unit. This unit consists of a storage buffer and a 'smart pump' which allows our computer controlled dosing pump to adjust to speed variations in the asphalt cement feed pump. This interactive linkage ensures that the correct amount of IntegraBase will be injected into the asphalt cement feed line in exact tandem with any variations in the pumping of the bulk asphalt cement in the feed line to assure optimal dosage at all times.

Once the correct amount of the Resperion Modifier has been accurately introduced into the asphalt cement feed line, we must only ensure that it is completely dispersed throughout the asphalt cement to ensure superior performance in every cubic meter of hot mix. Resperion achieves optimal dispersement by installing a static blender in the asphalt cement feed line of your batching plant. This short, maintenance-free and precision-engineered unit fits neatly into your existing plant arrangement and guarantees that your project is successful.

5.3 On-Site Storage of IntegraBase
Since the IntegraBase chemical reaction is a "thin-film" chemistry, there are no bulk storage limitations in terms of time or temperature. IntegraBase is a completely soluble product. Unlike polymers, IntegraBase never experiences settling of chemical constituents; this alleviates the need of having to mix the product before it is added to the bitumen. The implementation of IntegraBase doesn't require shear when mixing the modifier and asphalt. IntegraBase can be stored indefinitely, as there is no known shelf-life. Over time the IntegraBase modifier may form a thin skin on top, which is completely dissolvable with a little mixing or stirring. IntegraBase can be stored in any material including: plastic, rubber, metal, etc. – the product is non-reactive, enabling a wide variety of storage options. IntegraBase can be frozen, freeze thawed for storage without any negative effects to the product.

5.4 Blending Parameters

It is very important that the IntegraBase modifier be pumped at above 75^0F (24^0C), anything lower can lead to burned out pumps and other problems. Ideally, the product should be about 90-100^0F (32-38^0C); there is not a lot of effort necessary to get the product to this temperature as there are numerous heating options available depending on the storage medium being used. Some options can include blankets, pads or even bayonet heaters.

There are no issues with IntegraBase potentially causing damage to the equipment of the plant. The product contains no fines to disrupt valves or lines. The metals in the product are very pure (HP-High Purity,) which don't create any buildup.

The ideal temperature to mix IntegraBase with aggregates and bitumen are between 135^0C and 145^0C (275^0F and 293^0F). If temperatures reach 150^0C or above, there will be a pungent odor from the mixing. The odor is not harmful, but can be objectionable for some of the workers at the plant.

There are no changes to the mixing times compared to that of normal practices.

5.5 Cure Time & Storage Options

Typically, allowing the IntegraBase treated mixture to cure for 30 minutes will provide more than enough time for the majority of the chemical reaction to occur. Usually this is not much of an issue as transportation times between the plant and site will suffice. If the manufacturing of the asphalt is being done on-site, it is a good idea to store the asphalt in silos or trucks for approx 30 minutes to allow the reaction to occur.

It is not a good idea to store the IntegraBase treated mixture for extended periods, as initially the pen of the asphalt increases during mixing, but with time, the asphalt will harden. We always recommend that IntegraBase treated asphalt be laid down the same day that it is produced. If the treated asphalt does need to be stored, it is possible to cut the reaction by using a CO_2 float between the asphalt and a tarp in a truck, or on top of a silo.

Since IntegraBase mixtures are mixed at a slightly lower temperature, it is important to take this into consideration for travel time to the job site. If the trip is going to be a long one, it is advisable to use a tarp to allow the mixture to retain it's temperature.

5.6 Transportation to Site

There are no special transportation requirements for IntegraBase modified asphalt. All normal procedures can be practiced. Release agents are not needed with IntegraBase modified mixes. In most cases, IntegraBase can make the asphalt easier to load and unload. IntegraBase does not make the asphalt sticky, or difficult to work with in any way.

5.7 Laydown and Compaction

The normal specified procedures for the lay down activities of asphalt concrete base are to be followed. Lay down and compaction is performed using conventional equipment and construction techniques. In spite of the higher strength of the modified mix, the workability of the material in terms of compactability and obtaining optimum density should be equal or superior to that for the same unmodified mix.

IntegraBase modified asphalt can be left uncovered in moderate temperature conditions for 30-60 days before being capped by a wearing course or a seal. It is important that there is a cover planned and it is followed through, as sometimes once the road is open for traffic, the need for a seal or overlay is forgotten.

6. Field Testing

6.1 Procedures

All typical procedures that would be practiced for an actual IntegraBase implementation should be followed for a field test. Here are the changes that are made for an IntegraBase implementation compared to that of a typical, untreated asphalt implementation:

Dosing

The Resperion Modifier is designed to be added to the asphalt cement at a rate of 2% by weight of the asphalt cement used. While small variations in the dosage rate will not affect overall performance, optimal dosage is best achieved through the use of the Resperion Automatic Dosing Unit. This unit consists of a storage buffer and a ‘smart pump’ which allows our computer controlled dosing pump to adjust to speed variations in the asphalt cement feed pump. This interactive linkage ensures that the correct amount of Resperion Modifier will be injected into the asphalt cement feed line in exact tandem with any variations in the pumping of the bulk asphalt cement in the feed line to assure optimal dosage at all times.

Mixing

Once the correct amount of the Resperion Modifier has been accurately introduced into the asphalt cement feed line, you must only ensure that it is completely dispersed throughout the asphalt cement to ensure superior performance in every cubic meter of hot mix. Resperion achieves optimal dispersement by installing a static blender in the asphalt cement feed line of your batching plant. This short, maintenance-free and precision-engineered unit fits neatly into your existing plant arrangement and guarantees that your project is successful. The optimal mixing temperature for IntegraBase is in the range of 135^0C and 145^0C (275^0F and 293^0F)..

Lay down and Compaction

The normal specified procedures for the lay down activities of asphalt concrete base are to be followed. Lay down and compaction is performed using conventional equipment and construction techniques. In spite of the higher strength of the modified mix, the workability of the material in terms of compactability and obtaining optimum density should be equal or superior to that for the same unmodified mix.

6.2 Testing Tips

6.2.1 Aggregates, Asphalts, and Subgrades to be Cautious About

Aggregate selection is typically a very important process when designing a road, but there are some important characteristics that need to be looked at. Aggregates that are hydrophilic in nature must be looked at very carefully, with tests suggested to see how much IntegraBase can help the binding properties vs. untreated asphalt. Lime may need to be used in the mix if the aggregates are too hydrophilic.

The only asphalt that can pose a problem for IntegraBase (as for untreated mixes as well) are paraffinic asphalts. Under low temperatures, paraffinic asphalts have the tendency to crystallize, which can be a huge problem – this can be a bigger problem than cracking.

Chinese asphalts are widely known to be paraffinic in nature and should be avoided if possible.

When assessing a subgrade, it is important to watch for plastic soils. To do this, a liquid and plastic limit test must be run (Autenburg Limit Test.)

All in all, it is very important to know all of the variables of the test beforehand. Always look into asphalt, aggregates, wear course, subgrade, traffic, etc. It can be very difficult to know when you are being put into a compromising situation. At a minimum, always make sure that the control for the test will be subjected to the same design parameters, location, traffic, etc.

6.2.2 Testing Parameters

The most important parameter for a field test is that the length of the test section be at least 1 Kilometer in length. It is important that modified asphalts be produced in more of a continuous production environment rather than a start/stop. The results will tend to be better, and are more telling of what the results would be in a full-scale implementation.

The minimum thickness to be tested in a base course or binder course is 10cm; this is no different than a normal implementation. The width of the test strip does not matter, as at least 1 full lane would always be constructed for a test.

When designing or approving a test for IntegraBase, the most important thing to look at is that it is being tested in similar conditions to the control. It is important that similar traffic types, weather patterns, moisture, shade, sun, hills, etc. are all taken into consideration. That is the only to fairly assess IntegraBase against a control material.

6.3 Application: Base Course

Introduction to an Asphalt Treated base (ATB)

Asphalt treated base (ATB) is a dense-graded HMA with a wide gradation band and lower asphalt content (2.5 - 4.5 percent by weight of aggregate) intended for use as a base course. ATB costs less than typical HMA mixes because it can be produced with less expensive aggregates and lower percentages of asphalt binder. In addition to the site paving benefits, ATB can be advantageous because it can provide:

- *A waterproof barrier to prevent fines infiltration into the subgrade and pavement structure*. If water accumulates in the subgrade, the repetition of pavement loading can cause subgrade fines to migrate into the base and pavement structure. This can clog the base layer, which impedes drainage and create voids in the subgrade into which the pavement may settle.

- *An alternative to untreated base material*. Structurally, ATB is about three times as strong as an untreated granular base (such as crushed surface base or top course). Therefore, it is possible to use thinner layers for the same structural support, which can save on excavation costs. In some cases a layer of aggregate base is still needed to provide material to fine grade and to provide a smooth surface on which to pave.

The costs savings of using ATB can add up quickly. On a site that must export material (excess cut), an ATB pavement design can save a considerable amount of excavation, hauling and disposal costs. On a site that must import material (excess fill), ATB can be used to build the pavement over more marginal subgrades (i.e. a structure of gravel borrow and ATB can replace thicker crushed aggregate sections).

Important Considerations when Substituting ATB for Crushed Aggregate

- *The minimum recommended crushed aggregate base thickness is 4 inches.*
- *The minimum recommended ATB thickness is about 4 inches.* ATB gradation and nominal maximum aggregate size specifications are quite loose, however pavement layers thinner than about 2-3 times the nominal maximum aggregate size may be difficult to compact, tear under the screed, and rollers may crush the larger particles during compaction.
- *Consider the original purpose of the crushed aggregate.* Sometimes aggregate base is needed to (1) provide material to fine grade and to provide a smooth surface on which to pave or (2) provide frost protection. In these situations, ATB should not be substituted for crushed aggregate base.
- *Consider the characteristics of the particular ATB being used*. ATB specifications are quite broad and allow for a wide choice of gradation and aggregate quality. For instance, the nominal maximum aggregate size can be anywhere from about 1.5 inches down to 0.375 inches; the gradation can either be fine or coarse; and the aggregate can either be crushed or not crushed. In general, do not assume anything more than what is specified.

7. Pavement Design

7.1 Overlay Guidelines

When implementing an IntegraBase base or binder course, the overlay should be designed with characteristics such as friction, smoothness, noise control, and drainage in mind. Often, rut resistance is something that is designed into the surface course, but when using IntegraBase, the base or binder course provides the rut resistance. In addition, the overlay should prevent the entrance of surface water into the underlying base, subbase and subgrade. Resperion recommends using a flexible wear course, and not using it for a load carrying member of the pavement design.

IntegraBase base or binder courses can be used with any wear course. As long as the overlay can seal off the base course, and provide adequate friction and drainage, there should be no problems with the overlay.

Depending on the traffic and loads, the most ideal overlay is a seal (chip, fog, slurry, etc.) as these provide drainage and friction, and will not rut. However, these types of overlays are not ideal for many different designs or implementations. Here are two surface courses that Resperion recommends for different climates:

For wear courses where the climate tends to be more subarctic, Resperion recommends using a hot rolled asphalt wearing course. This type of wear course has become very popular in Europe, most notably the UK where they have created a standard for it (BS-594). In terms of what kind of asphalt to use, we would recommend an 80/100 pen bitumen, as it needs to be softer for the colder temperatures.

For wear courses where the climate tends to be more tropical, we would suggest using a SMA (Stone Mastic Asphalt) wear course. This type of wear course has recieved a lot of acclaim as of late, and has been used a lot in the US as well as Europe. It is a strong wear course due to the gradations of the aggregates, and performs well in hot climates. We would typically recommend a 60/70 pen bitumen for a SMA.

7.2 Application: Base Course

Introduction to an Asphalt Treated base (ATB)

Asphalt treated base (ATB) is a dense-graded HMA with a wide gradation band and lower asphalt content (2.5 - 4.5 percent by weight of aggregate) intended for use as a base course. ATB costs less than typical HMA mixes because it can be produced with less expensive aggregates and lower percentages of asphalt binder. In addition to the site paving benefits, ATB can be advantageous because it can provide:

- *A waterproof barrier to prevent fines infiltration into the subgrade and pavement structure*. If water accumulates in the subgrade, the repetition of pavement loading can cause subgrade fines to migrate into the base and pavement structure. This can clog the base layer, which impedes drainage and create voids in the subgrade into which the pavement may settle.

- *An alternative to untreated base material*. Structurally, ATB is about three times as strong as an untreated granular base (such as crushed surface base or top course). Therefore, it is possible to use thinner layers for the same structural support, which can save on excavation costs. In some cases a layer of aggregate base is still needed to provide material to fine grade and to provide a smooth surface on which to pave.

The costs savings of using ATB can add up quickly. On a site that must export material (excess cut), an ATB pavement design can save a considerable amount of excavation, hauling and disposal costs. On a site that must import material (excess fill), ATB can be used to build the pavement over more marginal subgrades (i.e. a structure of gravel borrow and ATB can replace thicker crushed aggregate sections).

Important Considerations when Substituting ATB for Crushed Aggregate

- *The minimum recommended ATB thickness is about 4 inches.* ATB gradation and nominal maximum aggregate size specifications are quite loose, however pavement layers thinner than about 2-3 times the nominal maximum aggregate size may be difficult to compact, tear under the screed, and rollers may crush the larger particles during compaction.

- *Consider the original purpose of the crushed aggregate.* Sometimes aggregate base is needed to (1) provide material to fine grade and to provide a smooth surface on which to pave or (2) provide frost protection. In these situations, ATB should not be substituted for crushed aggregate base.

- *Consider the characteristics of the particular ATB being used.* ATB specifications are quite broad and allow for a wide choice of gradation and aggregate quality. For instance, the nominal maximum aggregate size can be anywhere from about 1.5 inches down to 0.375 inches; the gradation can either be fine or coarse; and the aggregate can either be crushed or not crushed. In general, do not assume anything more than what is specified.

8. Issues With Implementation

8.1 Temperature

The main flaw of asphalt cement is its steep temperature-viscosity curve. A relatively small change in temperature will change a hard and brittle asphalt into a soft and flowing material (from a cracking material into a rutting material.)

The chemical reaction that occurs in the IntegraBase modification process greatly increases the molecular weight of the asphalt cement which greatly flattens the temperature viscosity curve. This reduces the sensitivity of the asphalt to temperature changes, and allows the choice of an asphalt grade that is better at high and low temperatures.

IntergraBase performs best in high-temperature implementations, and marginally improves asphalt in extreme low-temperature scenarios. Because of this, Resperion typically recommends not to use IntegraBase when looking for large improvements in extremely low temperature implementations. It is feasible that there can be benefits to using IntegraBase in a scenario like this, but in extreme cases we would normally suggest a very high pen asphalt that is better suited to handle the freezing temperatures. However, Resperion likes to look at each of these scenarios separately as IntegraBase can help quite a bit in scenarios with temperature fluctuations, or when there are only short periods of extremely cold weather.

8.2 Oxidation

The chemical reaction that IntegraBase initiates with the bitumen and aggregates is that of an Oxidant. Since oxygen is one of the primary catalysts of the IntegraBase reaction, the reaction will continue to occur when there is oxygen present. However, the majority of the reaction takes place in the first 30-40 minutes after the mixing, and any further oxidation will be minimal and will occur over a long period of time. This is the sole reason that IntegraBase failed in numerous wear course tests 15 years ago; prolonged exposure to oxygen increases the aging of IntegraBase modified asphalt, leading to premature hardening. However, it is well understood that oxygen is unable to penetrate below 19mm in asphalt structures (appendix B), and that there are not enough moles of oxygen contained in the typical 5% air voids to initiate any type of oxidation (appendix C). In a typical binder course application, IntegraBase modified HMA would be covered by an overlay of at least 50mm, more than 2 times the required coverage to prevent any oxidation. To date, there has never been a case of premature oxidation of IntegraBase modified HMA when there has been an overlay or seal applied.

8.3 Wear Course

In every IntegraBase implementation it is required that some type of wear course or seal is placed above the treated base or binder course within 30 days of paving. Depending on the temperatures, it could be left uncovered longer, but there is no reason to take chances. In warm weather, asphalt tends to cure faster, especially with high winds.

Any type of seal or overlay is sufficient; as long as the base or binder course is sealed from oxygen, there will never be a problem with IntegraBase treated HMA.

9. Asphalt Additives

9.1 Trinidad Lake Asphalt

A natural occurring asphalt found in Venezuela. Used as a by-product in other asphalts, mainly by the Germans. This asphalt doesn't have any air voids, which results in a very brittle pavement.

9.2 Gilsonite

This is a natural occurring bitumen (Rock solid mineral) which can be found in Sierra Nevada's, etc which can't be pumped in traditional asphalt applications. It only hardens the asphalt which reduces flexibility and fatigue. It replaces anywhere from 2-15% of binder and will typically improve marshall stabilities 10-40%.

9.3 Sasobit

Sasobit is a bitumen additive of Sasol Wax. It acts as a liquefier for neat and polymer modified bitumen and enhances workability and reduces compaction resistance through a significant viscosity decrease. Several new processes have been developed to reduce the mixing and compaction temperatures of hot mix asphalt without sacrificing the quality of the resulting pavement. One of these processes utilizes Sasobit, a synthetic long chain Fischer-Tropsch wax. Sasobit can be blended with the binder at a terminal or in the contractor's tank, introduced in a molten form, added with the aggregate, or pneumatically blown into a drum plant. The addition of Sasobit does not affect the Resilient Modulus of an asphalt mix nor does it increase the rutting potential of an asphalt mix.

9.4 Polymers

Polymers are manufactured in a chemical process to combine particular molecules in a way that would not occur naturally. Although various synthetic polymers have been capable of being produced since the early part of this century it is the more recently developed polymers that are now being used to modify bitumens and produce the new bituminous binders. The new polymers being the result of research and development by the large petro-chemical industries.

Polymer additives do not chemically combine or change the chemical nature of the bitumen being modified, apart from being present in and throughout the bitumen.
What polymers will do is change the physical nature of bitumen - they are able to modify such physical properties as the softening point and the brittleness of the bitumen.
Elastic recovery/ductility can also be improved. This in turn will alter the properties of the aggregate / bitumen mixture in which the modified bitumen is used. These criteria are important in a mix in relation to wheel track rutting at high temperatures and fatigue cracking at low temperatures due to the brittleness of the mix.

9.4.1 Types of Polymers:

SBS (Styrene Butadiene Styrene) - This is a thermoplastic rubber.
SBS is a copolymer that you will come across in bitumen modification, it was originally

developed for use in the production of tires and shoe soles, but is suitable for the modification of bitumen.

SBR (Styrene Butadiene Rubber) - SBR Latex Polymers contain emulsion polymerized random copolymers of styrene and butadiene in a water-based system. In latex form, the SBR particles are extremely small (averaging .5 microns), exposing a very high surface area to the asphalt for complete mixing. As a result, the physical dispersion of the polymer particles is rapid and thorough.

EVA (Ethylene Vinyl Acetate) - This is not regarded as part of the thermoplastic rubber group but is still thermoplastic in its nature. One of the uses for this type of polymer are the "hot melt" glues, the sticks of which you may be familiar with in "D.I.Y" hot melt adhesive guns. The most common grade of EVA for bitumen modification, for road pavement materials, is the classification "150/19". This classification means it has a melt flow index of 150 and a vinyl acetate content of 19%, how much you include in the bitumen to be modified for optimum benefit can be debatable, but 5% by weight is a commonly quoted figure.

9.4.2 Common Issues With Polymers

The possible problems with modified bitumens are mainly in the storage of the bitumen, mixing temperatures, and the length of time the material is held at elevated temperatures before laying.

The blending of bitumen and polymer is not an easy process, so modified bitumen is usually purchased by the quarry in a ready blended form from the bitumen supplier. This means the quarry normally has to take a 20 ton tanker load, and with an 8% binder content asphalt this will produce 250 tons of asphalt. This means small tonnages of most modified bituminous materials are not financially feasible.

It is usually necessary for the modified bitumen to be held in a tank that is capable of being agitated in some way, as the polymers being of a different density to the bitumen tend to separate if kept in storage for prolonged periods.

The polymer additive can be destroyed by too high a temperature in mixing, or by being held at a high temperature for a long period of time after mixing, even the binder storage times should be kept as short as possible or deterioration of the polymer may take place.

10. IntegraBase and Performance Grading (PG)

Resperion's IntegraBase asphalt modifier makes it possible to improve lower-performing performance-graded asphalt binders to the point where they can meet stringent PG specifications for Superpave mixes. Not only can IntegraBase improve the PG specifications, but it also improves the resilient modulus and fatigue resistance of the asphalt, further improving rut resistance and flexibility for base and binder courses.

10.1 Historical Asphalt Grading

Asphalt cements have historically been graded by two empirical tests; penetration and viscosity. These tests were developed over time using experiences with asphalt pavements. These tests attempt to repeat past successes, and avoid past failures. Empirical tests work as long as all of the conditions at the time of the test development remain unchanged.

Unfortunately, this is not true of our asphalt pavements today. Penetration and viscosity tests were developed in an era of less traffic and significantly lower pavement loadings. Trucks of yesteryear were limited to 72,000 lb. and rode on bias ply tires with tire pressures of 75 psi. Today, truck weights exceed 80,000 lb and radial tires are inflated to 125 psi. A 10% increase in truck weight results in a 40% increase in stresses applied to the pavement. These factors, along with the numbers of heavy trucks traveling roads across the globe, subject asphalt pavements to stresses, which result in rutting and premature failure.

10.2 Superpave Performance Grading (PG) System

The Superpave PG system was developed as part of the Superpave research effort to more accurately and fully characterize asphalt binders for use in HMA pavements. The PG system is based on the idea that an HMA asphalt binder's properties should be related to the conditions under which it is used. For asphalt binders, this involves expected climatic conditions as well as aging considerations. Therefore, the PG system uses a common battery of tests (as the older penetration and viscosity grading systems do) but specifies that a particular asphalt binder must pass these tests at specific temperatures that are dependant upon the specific climatic conditions in the area of intended use.

Superpave performance grading is reported using two numbers – the first being the average seven-day maximum pavement temperature (in °C) and the second being the minimum pavement design temperature likely to be experienced (in °C). Thus, a PG 58-22 is intended for use where the average seven-day maximum pavement temperature is 58°C and the expected minimum pavement temperature is -22°C. Notice that these numbers are pavement temperatures and not air temperatures.

10.3 The IntegraBase Effect

It is the aim of every asphalt formulator to be able to take the most economic source of asphalt and enhance the high temperature properties and comply with low temperature requirements in fulfilling PG targets. IntegraBase makes the achievement of this objective a reality while providing for additional technical benefits at a minimal cost.

The following table illustrates that blending IntegraBase with asphalt binder can result in a two to three grade improvement in the upper and lower temperature performance, although these results may vary based on the properties of the asphalt binder used. The unmodified asphalt binder used in this test was an Egyptian 60/70 pen:

	Unmodified	**IntegraBase Modified**
Actual PG Grade	58-04	75-16
PG Classification	58-04	70-16

Complete test results can be found in section 11.7

IntegraBase also provides for a large increase in Resilient Modulus and fatigue life - in most cases, IntegraBase will improve the Resilient Modulus by 100% and the fatigue life by 50%. With this additional pavement strength generated through the use of the IntegraBase modifier, it is possible to reduce the maximum strains which develop in the pavement due to wheel-loads. This translates into a superior-performing pavement that will be resistant to both pavement deformation and pavement cracking.

Additionally, the improved pavement strength and elasticity will increase the number of standard axle loads which can be carried by the IntegraBase modified pavement throughout its useful lifetime; this can result in substantial life-cycle savings in terms of pavement longevity and decreased maintenance.

10.4 Polymer Modified PG vs. IntegraBase Modified PG

Polymer modification, which is a commonly used system to change the properties of asphalt binders, can increase the cost of the binder anywhere from 30% to over 100%. This increase can make a significant impact on the cost of the hot mix asphalt (HMA,) typically raising the price 25% to over 50%. Because of the large increase in cost, the use of Polymer Modified asphalt is limited to use as a wear course modifier in high stress or extreme climate applications. The use of Polymers in base/binder applications wouldn’t be cost effective, nor could it match the benefits of IntegraBase from Resperion. The following table summarizes up how Polymer Modified PG compares to IntegraBase modified PG:

	Polymer Modified PG	**IntegraBase Modified PG**
Price	Very expensive – can increase costs as much as 100% depending on concentration and polymer.	Quite inexpensive – under 10% increase in cost. Cost can be offset by thickness reduction of base/binder course.
Dosing & Mixing	Polymers are very sticky, which make them difficult to pump and can lead to clogged valves and messy equipment. Polymers also require higher mixing temperatures which increase costs and raise environmental issues.	IntegraBase’s low-viscosity makes it easy to add via the asphalt feed line without any sticky mess. IntegraBase can be blended at lower temps, decreasing production expenses.
Hauling	PMA (Polymer Modified Asphalt) will stick to truck beds if no release agents are used. Tarps must also be used so the PMA does not cool off and the mixture doesn’t dry out.	The same hauling procedures for unmodified asphalt can be used with IntegraBase modified asphalt. Release agents are not needed, nor are tarps, unless weather dictates to do so.

Laydown & Compaction	Laydown and compaction can be very difficult due to the sticky characteristics of PMA. There are strict minimum temperatures that must be met for: PMA delivery, surface temperature, and the paver screed; any deviation will result in compaction problems and PMA sticking to construction equipment.	In spite of the higher strength of the IntegraBase modified mix, the workability of the material in terms of compactability and obtaining optimum density is superior to that of PMA and even unmodified mixes due to the lubricating effects of IntegraBase.

Not only is IntegraBase cost effective, increasing the cost of a typical mix by less than 10%, rational pavement design techniques confirm that base and binder course layers constructed with IntegraBase can be reduced in thickness by up to 40%, while achieving an equal or greater number of equivalent standard axle loads (ESAL's) as conventional materials. Since the cost of the materials saved exceeds the cost of the MMC by a wide margin, Resperion enables you to build the same road for less money.

10. Test Results

***** Note: Prior to 2003, the IntegraBase Modifier was sold under the name Chemcrete, as some of these tests will refer to the old name of the product.***

10.1 Resilient Modulus

Resilient Modulus of DBM Mix with Conventional and Modified Bitumen (Central Road Research Institute, India 7/2005)

Set of Results	Resilient Modulus, MPa @ 25°C	
	Conventional Binder	Modified Bitumen with 2% Modifier
1	2199	2851
2	2241	2723
3	2273	2656
4	2262	2545
5	2255	2492
Mean	2246	2653

Resilient Modulus Properties (Louis Berger Group, Afghanistan 10/2003)

Property	Azerbaijan-Baku		Iraq-Kerkuk		Pakistan-Atock	
	Un-modified	IntegraBase-modified	Un-modified	IntegraBase-modified	Un-modified	IntegraBase-modified
Mr at 77F, psi	340,000	400,000	698,000	755,000	500,000	760,000
Mr at 104F, psi	87,000	147,000	155,000	342,000	105,000	260,000

Summary of the Resilient Modulus Properties (Peter A. Sebaaly, Ph.D, University of Nevada-Reno 12/2005)

Property	Untreated Mix	IntegraBase Mix
Resilient Modulus at 40°F, ksi	1380	1470
Resilient Modulus at 77°F, ksi	390	520
Resilient Modulus at 110°F, ksi	77	300

10.2 Marshall Stability

Marshall Stability Tests (University of Nottingham, 11/1987)

Specimen	Void Content (%)	V.M.A. (%)	Stability (kN)	Flow (mm)
100 pen. Untreated	5.9	23.2	2.9	2.5
100 pen. Chemcrete	5.8	23.3	4.3	2.7
70 pen. Untreated	5.9	23.3	4.9	2.6
70 pen. Chemcrete	6.3	23.6	7.6	3.0

Test results according to Marshall (General Directorate of National Roads and Highways, Białystok Branch, Poland 7/2004)

	BA/20 in bind.ag. w/out	BA/20 in bind.ag. w/ chemcrete	
	after 24 hrs	after 24 hrs	after 5 days
Stability [kN]	18,1	20,3	21,3
Flow [mm]	3,4	3,2	3,7
Free space %	5,7	6,0	6,0
Condensation volume [g/cm^3]	2590		

Marshall Stability Tests (Louis Berger Group, Afghanistan 10/2003)

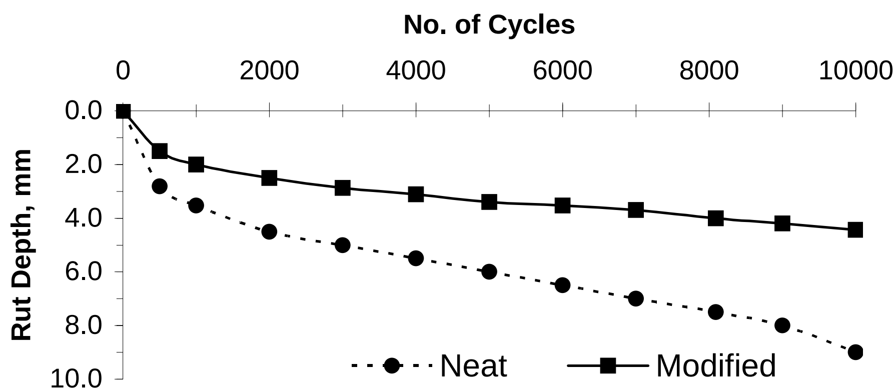
Specimen	Void Content (%)	V.M.A. (%)	Stability (lb)	Flow (.25 mm)
60/70 pen - Untreated	6.0	13.8	1867	10
60/70 pen with IntegraBase	4.8	12.7	3039	9

10.3 Wheel Tracking

Wheel Tracking Tests (University of Nottingham, 11/1987)

	Rate of Tracking (mm/hr)	
Bitumen	**Untreated**	**Chemcrete**
100 pen.	8.8	3.2
70 pen.	3.8	1.4
50 pen.	2.3	.6

Wheel Tracking Test (Central Road Research Institute, India 7/2005)



10.4 Moisture Sensitivity

Moisture Sensitivity of Romanian 60/80 Bitumen (Peter A. Sebaaly, Ph.D, University of Nevada-Reno 12/2005)

Property	Untreated Mix	IntegraBase Mix
Unconditioned Tensile Strength, 77°F, psi	98	129
Moisture conditioned Tensile Strength, 77°F, psi	58	82
Retained Strength Ratio, %	60	64

Summary of the moisture sensitivity data of the Chemcrete and control mixtures (Peter A. Sebaaly, Ph.D, University of Nevada-Reno 1/2001)

Mix Type	Mix Condition	Air Voids (%)	Saturation (%)	Tensile Strength (psi)	Average TS (psi)	TS ratio (%)
Control	Dry	6.0 5.9 7.1	na na na	129 132 148	136	40
	Conditioned	5.9 6.6 6.3	67 73 67	50 55 57	54	
Chemcrete	Dry	6.9 8.0 6.8	na na na	232 192 218	214	49
	Conditioned	6.2 7.3 8.0	58 63 55	96 118 98	104	

10.5 Fatigue Analysis

Fatigue Life (in terms of number of cycles) of DBM Mixes (Central Road Research Institute, India 7/2005)

Type of Mix	Low Strain (300 micron)	High Strain (700 micron)
DBM with 60/70 bitumen	56243	12566
DBM with IntegraBase modifier	69741	14576

Summary of the Fatigue data at 68°F of the Chemcrete and control mixtures (Peter A. Sebaaly, Ph.D, University of Nevada-Reno 1/2001)

Sample	Air Voids (%)	Strain Level	Strain (microns)	Cycles to Failure	Initial Modulus (ksi)	Final Modulus (ksi)
Control Mix						
Average	6.4	high	453	2.04E4	1,177	588
STD*	0.2		17	7.35E3	81	40
CV**	3		4	36	7	7
Average	6.6	low	275	1.87E5	1,293	647
STD	0.2		6	1.71E4	119	60
CV	3		2	9	9	9
Chemcrete Mix						
Average	6.3	high	447	1.54E4	1,377	688
STD*	0.2		26	5.87E3	40	20
CV**	3		6	37	3	3
Average	6.2	low	256	2.23E5	1,540	770
STD	0.2		5	8.42E4	44	22
CV	3		2	38	3	3

* STD: Standard deviation
** CV: Coefficient of variation = (standard deviation/average

10.6 Marginal Aggregates

Summary of Marshall Stability and Flow Properties using Concrete Sand (Army Corps of Engineers, 1/1981)

	8.5% Untreated AC-20		8.5% Chemcrete AC-20	
Cure	**Stability (lb)**	**Flow (.01 in.)**	**Stability (lb)**	**Flow (.01 in.)**
1-day (room temp)	261	17	305	18
7-day (room temp)	302	14	348	14
7-day (140^{o}F oven temp)	641	7	1133	11

Summary of Marshall Stability and Flow Properties using 75% Chert Gravel and 25% Concrete Sand (Army Corps of Engineers, 1/1981)

	7.7% Untreated AC-20		7.7% Chemcrete AC-20	
Cure	**Stability (lb)**	**Flow (.01 in.)**	**Stability (lb)**	**Flow (.01 in.)**
1-day (room temp)	1152	10	1520	12
28-day (room temp)	1152	8	1671	12
28-day (140^{o}F oven temp)	1737	10	2603	10

10.7 IntegraBase Modified PG

Tests Results from PRI Laboratories
Unmodified Asphalt: 60/70 pen from Egypt
Modifier: IntegraBase, 2%
Date: October 10, 2004

AFTER RTFOT		Specification	Untreated	IntegraBase 2%
Dynamic Shear (G*/sinδ, 10 rad./sec.), kPa	@ 58°C	2.2 min.	11.55	--
	@ 64°C		4.574	--
	@ 70°C		*1.855*	4.281
	@ 76°C		--	1.910

PRESSURE AGING RESIDUE (100°C, 300 psi, 20 hr.)		Specification	Untreated	IntegraBase 2%
Dynamic Shear (G*•sinδ, 10 rad/sec), kPa	@ 28°C	5,000 max	*6,421*	6,167
	@ 31°C		4,902	4,340
Creep Stiffness, MPa (60 sec)	@ -6°C	300 max.	185	161.8
m Value		0.300 min.	0.310	.302
Creep Stiffness, MPa (60 sec)	@ -12°C	300 max.	*348*	271.2
m Value		0.300 min.	*0.261*	.280
Creep Stiffness, Mpa (60 sec)	@ -18°C	300 max.	*549*	--
m Value		0.300 min.	*0.222*	--
Actual PG Grade:			58-04	75-16
SUPERPAVE™ Binder Grade, PG:			58-04	70-16

MATERIAL SAFETY DATA SHEET

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Revision Date	April 1, 2004
Product Name	Resperion IntegraBase, IntegraSeal,
Product Identification Number(s)	N/A
Manufacturer/Supplier	Resperion LLC, San Mateo, California, 94402
Chemical Name	N/A
Synonyms(s)	N/A
Molecular Formula	N/A
Product Use	Asphalt Modification, Emulsion Modification
OSHA Status	Nonhazardous

2. HAZARDOUS INGRIDIENTS

Hazardous Ingredients	None. The precise composition of this mixture is proprietary. A more complete disclosure will be provided to a physician or nurse in the event of a medical emergency.

3. FIRE AND EXPLOSION HAZARDS

Flash Point	240 °C (COC)
Upper Flammable Limit	Not Determined
Lower Flammable Limit	Not Determined
Extinguishing Media	CO_2, dry chemical, foam
Special Firefighting Procedures	None
Unusual Fire & Explosion Hazards	None

4. HEALTH HAZARD DATA

Oral Toxicity	Greater than 5,000 mg./Kg. in rats
Eye Irritation	Not expected to cause eye irritation
Skin Irritation	Not expected to cause skin irritation
Other	Unknown
TLV	None established. Oil mist – 5 mg./cu. Meter. Manganese compounds, TLV 5 mg./cu. Meter. (Note: Toxicity values based on data from components. No manganese was detected in vapor space samplings under simulated paving conditions.)

5. EMERGENCY FIRST AID PROCEDURES

Skin	Wash with soap and water
Eye	Flush with water for 15 minutes
Inhalation	Remove to fresh air - see physician if irritation persists
Oral	Call a physician - do not induce vomiting
Additional	None

6. SPECIAL PROTECTION INFORMATION

Ventilation Procedure	Mechanical ventialation recommended
Gloves Protection	Neoprene or nitrile rubber gloves recommended
Eye Protection	Safety Glasses
Other Protection	None

7. PHYSICAL DATA

Vapor Pressure	Not determined
Specific Gravity	0.98 at 25 °C
Water Solubility	Negligible
Percent Volatile	Not Determined
Vapor Density	Not Determined
Evaporation Rate	Not Determined
Odor	Mild
Appearance	Dark colored liquid

8. STABILITY

Stability	Stable
Incompatibility	Oxidizing Agents
Polymerization	Will not occur
Thermal Decomposition	Oxides of Carbon and Manganese

9. SPILL OR LEAK PROCEDURES

Spill Procedures	Prevent entry into sewers and waterways. Pick up free liquid for recycle/disposal. Absorb small amounts of inert material for disposal.
Waste Disposal	If disposed of, this material is believed to be non-hazardous. Discharge, treatment or disposal may be subject to national, state, or local laws.

10. SPECIAL PRECAUTIONS

Special Precautions	None

11. TRANSPORTATION AND LABELING

Emergency Action Code	3 Z Non-Hazardous for transport purposes Not a substance or article under ADR Not a dangerous substance under IMO

12. OTHER INFORMATION

For other information, please contact Resperion at:
Resperion LLC
400 South El Camino Real, Suite 450
San Mateo, CA 94402
+1 650 375 8900

The information presented herin has been complied from sources considered to be dependable and is accurate to the best of seller's knowledge as of the date compiled. However, no representation, warranty, or guarantee is made as to its accuracy, reliability or completeness. It is the user's responsibility to satisfy themselves as to the suitability and completeness of such information for their own particular use. Resperion does not accept liability of any loss or damage that may occur from the use of this information.

Appendix B – Oxidation of Asphalt – AASHTO Vol. 48, 1979

The ultimate future of pavement recycling, however, will depend on economics. For recycling to become a dominate factor in the future reconstruction process for existing asphalt pavement structures, it will have to be cheaper, faster, and easier to reuse the present pavement materials than to remove, waste, and replace them.

* * * * *

VOLUME 48 – 1979

RECYCLING OF BITUMINOUS PAVEMENTS ON THE ROAD

GEORGE M. JONES[1]

Increasing costs of asphalts and aggregates have made the recycling of pavements necessary. Complete recycling involves removal of the pavement, crushing, adding asphalt and/or an asphaltic modifier together with new aggregate, if necessary. The mixture is then heated and relayed. Surface recycling involves heater scarification, the addition of an asphaltic modifier and rolling.

The effectiveness of any on the road recycling is a function of the judicious use of an asphaltic modifier and the compaction of the scarified pavement. The first modifier was marketed about 1961. In the past few years many modifiers have been developed. I know of 25; perhaps there are twice that many. Here are the general characteristics, Table 1. It is generally considered that the higher the aromatics the more effective the modifier.

The effects of different modifiers on a specific asphalt are different. Conversely, the effects of a specific modifier on different asphalts are

Table 1. Asphaltic Modifier Characteristics

Flash Point COC, Min.	180C (356F)
Viscosity, CS at 60C (140F)	10–50
Specific Gravity 15.6/15.6C (60/60F)	0.96–1.04
Pour Point, Min.	15.6C (60F)
Polar Compounds, Percent	5–15
Aromatics, Percent	65–80
Saturates, Percent	10–15
Asphaltines, Max. Percent	0.2

[1] Asphalt Paving Consultant, Salt Lake City, Utah.

Table 2. Core Slice Depths

Layer	Depth
A	0 – 6.4 mm (0 – 1/4 in.)
B	9.5 – 15.9 mm (3/8 – 5/8 in.)
C	19.1 – 25.4 mm (3/4 – 1 in.)
D	28.6 – 34.9 mm (1 1/8 – 1 3/8 in.)
E	38.1 – 44.5 mm (1 1/2 – 1 3/4 in.)

different, therefore, a single relationship cannot be valid for general use.

Coons and Wright (AAPT Volume 37, page 510) took cores from pavements from 1 to 13 years old. Each core was sliced in layers 6.4 mm (1/4 in.) thick parallel to the surface. The kerf was 3.2 mm (1/8 in.). Core slice depths are shown in Table 2. The relative viscosities of the extracted asphalt plotted against age in months is shown in Figure 1.

These data indicate that the rate of hardening of the asphalt below 19 mm (3/4 in.) in depth is insignificant. Therefore, if the asphalt in this upper portion of the pavement can be softened and returned toward its original condition the pavement will have additional useful life.

The recycling of bituminous pavements on the road is less expensive than removal and plant recycling. There is less interference with traffic.

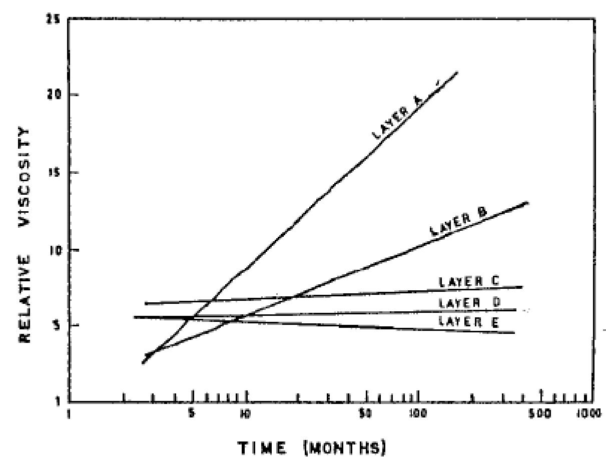


Fig. 1. Relative Viscosities.

Relative Oxygen Availability in a Dense Bituminous Macadam Pavement

Author: Patrick K. Clancey

April 21, 1997

Abstract:
The purpose of this paper is to determine whether or not the amount of oxygen contained within the air voids of a typical dense bituminous macadam pavement is sufficient to meet the theoretical oxygen requirements imposed by the Chemcrete reaction sequence.

Basis

This calculation will take as its basis a one cubic meter section of dense bituminous macadam roadbase composed of 95% aggregate, 5% bitumen and containing 5% air voids.

Part I: Determination of In Situ Oxygen

If 5% of our pavement is air voids, it contains a void volume of 0.05 cubic meters. Since there are 1000 liters in a cubic meter, this is identical to 50 liters of air space. From the Ideal Gas Law we can determine the number of moles of air which would be present within the void space of our typical pavement under normal atmospheric conditions (after compaction.)

$$n = PV/RT$$

$$= (1 \text{ atm}) (50L) / (0.08205 \text{ L atm per mole K}) (298 \text{ K})$$

$$n = 2.04 \text{ moles of air}$$

However, air is only 21% oxygen on a molar basis and it is only this oxygen component that is relevant in the Chemcrete reaction sequence. There fore, the amount of oxygen contained in our 5% void space can be found as follows:

$$\text{In Situ Oxygen Content} = (2.04 \text{ moles air}) (0.21 \text{ moles oxygen/mole air})$$

$$= \underline{\mathbf{0.43 \text{ moles } O_2}}$$

Part II: Determination of Manganese Content

If 5% of our basis pavement is air voids, then the remaining 95% is dense bituminous macadam. Assuming that DBM has a specific gravity of approximately 2.35, we can determine the amount of hotmix which would be required to construct the pavement:

$$(0.95 \text{ cu m DBM}) (1000 \text{ kg/cu m}) (2.35) = 2232.5 \text{ kg } \textit{Hotmix}$$

If our hotmix is 95% aggregate and 5% binder, we can determine how much bitumen is contained in our pavement:

(2232.5 kg hotmix) (0.05 kg bitumen/kg hotmix) = 111.6 kg *bitumen*

If the bitumen contains 2% Chemcrete Modifier by weight and that Chemcrete Modifier contains 7.5% manganese, we can determine the manganese present within the basis pavement as follows:

(111.6 kg bitumen) (0.02 kg Chemcrete/kg bitumen) (0.075 kg Mn/kg Chemcrete)
= 167 gm Mn

Since the manganese has a molecular weight if 54.94 gm/mole, we know that on a molar basis:

Manganese Content = (167 gm) / (54.94 gm/mole)
= **3.04 moles Mn**

Part III: Determination of Relative Oxygen Availability

Since the calculation in Part I indicated that 0.43 moles of molecular oxygen are present within the void space, we know that it is possible to produce a maximum of 0.86 moles (i.e. – twice this number) of ketones. Further, we know that the Chemcrete complex is a product of one manganese atom with two diketones (i.e. – four ketones.) This allows one to make the following comparisons:

Moles of Ketones Required to Complex Available Mn
= 4 x moles Mn
= 4 x 3.04
= 12.16

Ratio of Moles of Ketones Available to Moles of Ketones Required
= 0.86/12.16
= 0.071

These figures indicate that a sufficient amount of oxygen exists in the 5% void space to produce approximately only one-fourteenth as many moles of ketones as we have moles of manganese. Furthermore, if we were to consume all of the oxygen present within the pavement by converting it to ketones and then complexing those ketones with manganese to form the Chemcrete complex, only 7% of all the added manganese would be consumed in this manner.

Part IV: Assumptions

The calculations outlined above are predicated upon a number of key assumptions. These assumptions are enumerated below along with an estimation of the relative validity of both.

1. The Ideal Gas Law adequately characterizes the state of the air contained within the basis pavement. This assumption has been proven to be quite accurate because the relevant calculations have been repeated using the Redlich-Kwong equation (a more precise equation of state) and the result was unchanged. We have chosen to present the Ideal Gas Law calculations for the sake of simplicity.

2. The temperature used in the Ideal Gas Law was assumed to be 25^0C. Under normal conditions, the temperature of a base course would probably be 25^0C or lower. However, since the diffusion of atmospheric oxygen into the base course layers of an asphalt pavement is a decidedly slow process, one could assume that the basis pavement was placed at 150^0C and sealed "immediately" via the spraying of a tack coat and the placing of the upper pavement layers. In this case, the amount of air in the 5% voids would correspond to that which would occupy such a volume at 150^0C. Repeating all the calculations one finds that in this scenario the ration of ketones available to ketones required falls to less than 5%

3. We have further assumed that all of the available oxygen is consumed in forming ketones on the bitumen molecules. While this may not strictly be the case, we feel that it is a safe assumption because independent studies of the Chemcrete reaction mechanism/kinetic rate have shown (via infrared spectroscopy) that in the presence of manganese, the only relevant mode of oxygen uptake is through the formation of ketones.

4. Finally, we have assumed that the entire atmosphere present within the void space is air. Due to fuming and bitumen degradation, some of the gas contained within the voids may be hydrocarbon-based. However, in light of the rations calculated above, it is clear that the relative oxygen availability would be even lower if the atmosphere contained a substantial amount of hydrocarbons.

Part IV: Conclusions

Given the information presented above we can safely conclude that an insufficient amount of oxygen is present within the available void space of a dense bituminous macadam roadbase to sustain the Chemcrete reaction sequence. As such, on the basis of the first principals of chemistry, we can be certain that Chemcrete asphalt will not continue to gain in strength after compaction. This is so because one of the reactants (oxygen) which is essential to the cross-linking reaction that generates the high strength of Chemcrete asphalt is virtually absent from the void space within the roadbase. It should be bourn in mind that this entire exercise has been based solely upon the use of in situ oxygen and has neglected the oxygen uptake which occurs during the mixing, hauling, and laying processes. Therefore, we can conversely conclude that all of the strength increase associated with a Chemcrete roadbase is achieved by the time the material is compacted on site.