



---

# **High Strength Asphalt Concrete Bases – Improving Asphalt Pavement Performance with IntegraBase**

---

**October 29, 2008**

**Prepared by:**  
Josh Benveniste  
CEO  
Resperion

## Introduction

IntegraBase is an asphaltic modifier which when added to bitumen reacts chemically when mixed with the aggregate. The result is an asphalt with increased workability, a 50-200% increase in pavement strength, higher fatigue resistance (and therefore, longer life), and increased resistance to rutting and stripping. The use of IntegraBase also allows for the option of reducing pavement thickness (up to 40%) for equivalent properties of a full depth pavement. IntegraBase brings the temperature- viscosity curve more toward the horizontal, providing for an ideal solution to combat thermal cycling, one of the biggest issues experienced by asphalt pavements. Due to its improved bonding properties, IntegraBase modified asphalt can be used with inferior aggregates such as sand, and in-situ materials, to give the same or better performance and lifetime as ordinary asphalt roads constructed of well graded, quality aggregates.

## High Strength Modified Asphalt

Bitumen is an excellent material for roads. By chemical product standards, it is very inexpensive. It is flexible, an excellent coating material, self-healing and readily available. Bitumen is sold and used according to the hardness or softness of the particular bitumen. This characteristic is expressed as the specific bitumen's penetration number. Any one grade of bitumen has one basic flaw: it is unable, because of its narrow, useful, viscosity range to remain both soft in cold weather and hard in hot weather. This flaw has forced the pavement design engineers to compromise between cold and hot weather properties in a given pavement, simply because a given grade of bitumen cannot perform well at extreme cold and hot temperatures. If the engineer selects a hard bitumen, he will solve his summer problem (rutting) but the pavement will crack in the winter and vice versa. IntegraBase's catalyst product brings the temperature- viscosity curve more toward the horizontal. with this change in the viscosity slope, the engineer can now start with a softer, more viscose, bitumen and have a superior pavement at all temperatures.

While lower viscosity in cold weather is achieved by use of a softer bitumen from the refinery, higher viscosity in hot weather results because IntegraBase's product produces a catalytic reaction, which results in the formation of indestructible organic-metallic complexes. These complexes are permanent, additional chemical "links" between the bitumen molecular sheets or platelets which slide over each other. Moreover, because this process of ketone formation requires the "uptake" of oxygen in the asphalt mix, and the catalytic conversion of hydroperoxides at the sites at which these ketones are formed, new hydro- peroxides (the carrier of oxidation and pavement aging) are not formed. Indeed, existing hydroperoxides are permanently reduced. Thus, traditional oxidation, which ages a pavement, is permanently reduced. However, since IntegraBase modified asphalt is always used in sublayers of pavement, oxidation is never an issue, In brief, IntegraBase's catalyst product produces a better, tougher, and more durable pavement.

## IntegraBase Chemistry

The IntegraBase modifier is a liquid product which consists of an organic catalyst carried in a petroleum fluxing oil. It is, therefore, both easily pumpable and highly compatible with all bitumens. When the IntegraBase modifier is blended with bitumen and the modified bitumen is combined with aggregate, a series of catalytic reactions occur which permanently change the structure of the bitumen.

All bitumen is composed of asphaltenes, resins and oils. The asphaltenes in the bitumen tend to be in the form of two dimensional (flat) platelets which tend to agglomerate into stacks held together only by hydrogen bonding, a very weak form of bonding. Therefore, these platelets have the ability to freely slide over and under one another to give asphalt the distinctive flow properties which we all know so well. However, the IntegraBase catalyst causes new chemical bonds to be formed between these asphaltene platelets which permanently link together vertically adjacent platelets. This makes IntegraBase bitumen considerably stronger than ordinary bitumen and makes an IntegraBase asphalt pavement less likely to rut under hot summer conditions. It also contributes to the improved wet strength of the IntegraBase treated asphalt as well as the increase in service life of the treated asphalt pavement.

## The Effects on Modified Asphalt

By molecular change, the process substantially improves all the key properties of asphalt:

- **Compressive Strength:** The ability to withstand loads in an unconfined state, which is the most critical condition.
- **Tensile Strength:** The ability to withstand flexural ads, which lead to the cracking of pavement.
- **Stability:** The ability to withstand loads at elevated temperature.
- **Fatigue:** The ability to withstand repeated flexural loads, a critical property of an overlay of a road.
- **Adhesion:** The strength of the attraction of the asphalt for the aggregate (i.e., stone, sand, etc.) and the ability of is adhesion to withstand replacement by water.
- **Temperature Susceptibility:** The slope of the temperature-strength curve of an asphalt/aggregate mix which signals that the normal unmodified asphalt is changing from hard material to a soft material with a small change in temperature.

The measurement of each of the above properties is determined generally by the following tests, administered by most every state highway department and various foreign transportation departments under their respective ministries.

**Resilient Modulus:** The Resilient Modulus ( $M_R$ ) is a subgrade material stiffness test. A material's resilient modulus is actually an estimate of its modulus of elasticity (E). While the modulus of elasticity is stress divided by strain for a slowly applied load, resilient modulus is stress divided by strain for rapidly applied loads – like those experienced by pavements.

**Marshall Test:** The most common test of asphalt/concrete mix design expressed in pounds per square inch. The test allows for a minimum stability specification, which is normally 1800 pounds per square inch.

**Moisture Sensitivity:** This is the most widely used method for determining HMA moisture susceptibility: This is a test for adhesion, where a samples are evaluated for tensile strength at dry and moisture conditioned stages.

**Fatigue Test:** Repetitive flexure of either beams or cylinders of asphaltic/concrete (i.e., the asphalt combined with aggregate) to simulate the loading and unloading of an overlay over an extended period of time.

The most important single advantage of IntegraBase's process is the radically reduced susceptibility of the modified asphalt to temperature changes once laid on the road. The process increases high-temperature strength and low-temperature strength. Road-building and road maintenance authorities can use soft asphalts in order to gain cold weather properties which are needed (resistance to cracking) without losing high-temperature stability (resistance to rutting and shoving). This also saves energy during road-building as the contractor can mix and lay the pavement at lower temperatures.

## **IntegraBase Economic Benefits**

The chemical reaction resulting in IntegraBase strengthening the molecular structure, and thus improving all the key properties of asphalt, produces substantial economic benefits in three categories: sand and other marginal aggregates less costly than stone can be used, pavement thickness can be reduced, and alternatively, pavement life may be extended.

### ***The Use of Inferior Aggregates***

The problems related to the procurement of highly suitable, low cost, and well graded aggregates materials for the production of asphalt are quite severe in many areas of the world. This is due to the need to transport large volumes of quality material large distances to the road construction site because of a lack of adequate (in quality and quantity) local material. The high cost of transporting material forces road authorities in these areas to search for ways to construct acceptable pavements from lower quality local aggregates.

The stability and cohesive strength of an asphalt mixture depends upon both the stability of the mineral aggregate and the stability of the bitumenous binder. The lower the stability of the mineral aggregate, the greater the percentage of the stability which must be derived from the binder. This is precisely why IntegraBase is particularly well suited for use in pavements constructed with lower quality aggregates and sands. By linking asphaltene platelets with strong, irreversible bonds, the strength of bitumen treated with IntegraBase is improved to the point where IntegraBase sand or in-situ asphalt pavements can bear loads which are comparable to those born by roads constructed with high quality aggregates.

This point was well demonstrated by Perkins<sup>1</sup> of the United States Army Corps of Engineers who achieved over 400% improvement after seven days of curing at 60°C with a 40/50 penetration bitumen in a well-graded concrete sand. See table 1.

Table 1: Summary of Marshall Stability and Flow Properties Using Concrete Sand

Cure	8.5% AC-20 Asphalt		8.5% AC-20 Asphalt w/IntegraBase	
	Stability – lb	Flow 0.01 in.	Stability – lb	Flow 0.01 in.
7-day, (140°F)	112	12	635	10
10-day, (140°F)	111	11	902	12

**Depth Reduction**

The improved dynamic stiffness of IntegraBase asphalt and its reduced temperature susceptibility, make it an advantageous component of bituminous base and binder courses. The higher modulus demonstrated by IntegraBase asphalt gives it an improved capacity to distribute loads. This, in turn, will result in lower stresses on the unbound layers of the pavement and a lower tensile strain in the asphalt materials, resulting in a longer life for the road structure.

The increase in modulus can also be used to reduce the thickness of an IntegraBase modified pavement. By conducting a modulus and fatigue analysis of IntegraBase modified asphalt versus an unmodified mix, it possible to determine an equivalent thickness ratio, enabling the reuxtion of design thickness of bound materials by 15 to 40 percent without reducing the service life the pavement. Please see the section titled "Pavement Thickness Reduction Analysis," to see a more detailed example of how reductions can be substantiated.

**Prolonged Life**

As previously mentioned, the IntegraBase process permanently alters the rheological properties of bitumen in a beneficial manner. Specifically, the new bonding which results from the use of IntegraBase permits the construction of asphaltic pavements which can bear higher loads at higher service temperatures than conventional asphaltic materials while still demonstrating greater plastic flow at the point of failure. (With IntegraBase one can use a grade lower viscosity bitumen for this effect.) This property, which has been confirmed by many independent testing laboratories, indicates that IntegraBase asphalt is a strong, yet flexible, material which should offer greater durability than conventional asphalt.

No easy measurement is possible of the value of lifetime improvements in highway construction with improved asphalt as compared with standard asphalt. However, the stronger and more weather-resistant features of asphalt made with IntegraBase's process imply an extended life and reduced maintenance, especially in areas of temperature and moisture extremes.

A similar, yet more quantitative, result was also obtained by the Transport and Road Research Laboratory TRRL of the United Kingdom Department of Transport. In Materials Memorandum No. 131, Nunn, Powell and Colwill<sup>2</sup> used linear elastic theory to assess the critical strains at the underside of the bound layers and at the top of the pavement subgrade for both IntegraBase asphalt and conventional asphalt structures. These strains were then converted into deformation and fatigue lives by using the criteria established by Powell et al (1984)<sup>3</sup>. This analysis allowed TRRL to conclude that, "The use of IntegraBase binder in bituminous materials has a significant effect on the predicted life of the road structure (in terms of standard axles) increasing it by a factor of 4 to 6 over the same thickness of dense bitumen macadam. Hence, it gives a much greater assurance of achieving the design life for a given thickness of bituminous construction."

## IntegraBase Technical Benefits

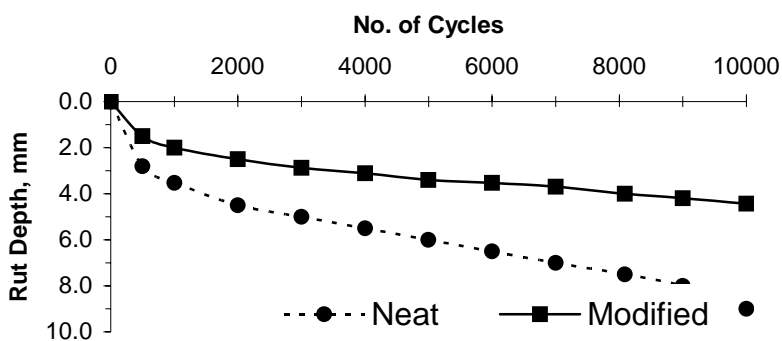
### **Rutting Resistance**

As mentioned previously, the catalytic reactions which occur when using IntegraBase make IntegraBase asphalt fundamentally different from conventional asphalt. By linking vertically adjacent asphaltene platelets, the IntegraBase process completely changes the rheological properties of the bitumen binder and subsequently the asphalt paving mixture.

Asphaltic pavements rut because the asphalt binder contained in a pavement exhibits an excessive amount of plastic flow at high temperatures which makes the structure, as a whole, unable to carry normal loads without deforming. One way to predict the ability of a pavement to resist rutting is to subject asphalt samples to the Hamburg Wheel Tracking Test.

The Central Road Research Institute's report<sup>4</sup> on IntegraBase shows the impressive rut resistance of modified asphalt versus unmodified asphalt. The relationship between number of cycles and rut depth was obtained for conventional as well as for modified mix, as shown in Figure-1. The rut depth observed after 10,000 cycles was 9.0 mm for conventional DBM mix. The rut depth reduces to 4.4 mm for modified mix after same number of cycles. This shows that Integrabase modifier improves the rut resistance property of the mix. There was a sudden steep change in slope after 9000 cycles in DBM mix with 60/70 binder. This may be attributed to the stripping of the aggregates. No stripping was however, observed after 10,000 cycles for modified mix. This is due to better tensile strength ratio of modified mix as compared to conventional mix because of improved water resistant characteristics of the modified mix.

Figure-1: Number of Cycles Versus Rut Depth



### **Anti Stripping**

Good adhesive properties are of vital importance to the durability of asphalt paving materials. When conventional bitumen is used, the asphalt will over time suffer from loss of binder, fretting, ravelling and generally deteriorate in wet climates. Such developments lead, through continuous deterioration, to the loss of resistance to fatigue and will eventually result in the development of fissures and potholes.

That the IntegraBase modifier can help prevent these problems can be shown by the data presented in Table 2 which summarizes the results of a saturation immersion tensile strain test which was conducted by the Dr Peter Sebaaly at the University of Nevada Reno<sup>5</sup>. The AASHTO T283 test compacts HMA samples to air voids between 6 and 8 % and evaluates the tensile strength of the compacted samples at the dry and moisture conditioned stages. Moisture conditioning consists of saturating the compacted

samples between 55 and 80% and subject them to a 16 hours cycle of freezing followed by a 24 hours of thawing at 60°C. The tensile strength ratio is evaluated as the ratio of the TS of the moisture conditioned samples over the TS of the dry samples.

Table 2: Summary of the Moisture Sensitivity Data

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

If the TSR is evaluated alone, then the IntegraBase mix is only 4% higher than the untreated mix. However, if the TSR is evaluated in conjunction with the actual tensile strength properties, it can be seen that the IntegraBase mix has a significantly higher unconditioned and moisture conditioned tensile strength properties. The moisture conditioned tensile strength of the IntegraBase mix is almost as high as the unconditioned tensile strength of the untreated mix. Based on this data, it can be concluded that, for this specific mix, the IntegraBase modifier improved the tensile strength of the mix in such a way that it will be as good as the untreated mix even after moisture conditioning. In other words, for this specific mix, a moisture-damaged IntegraBase mix is as good as an un-damaged untreated mix.

### **Workability**

As universally recognized, the overall quality of a finished asphalt pavement, both in terms of materials and workmanship, has a very significant affect on the integrity and durability of the road structure as a whole. The workability of a coated material, while almost impossible to define objectively, is a major factor in the determination of the quality of a finished pavement because, as a rule, the greater the stiffness and unworkability of the material, the greater the inherent level of defects in the finished road. However, the need for increased strength and deformation resistance in the face of increased traffic stresses has prompted a change to harder bitumens, to lower binder contents, and to finer aggregates. Unfortunately, each of these changes effectively reduce the workability of the paving material and subsequently the durability of the finished pavement and therefore lead to uneconomic, short life- spans for such road surfaces.

In the face of this problem, the asphalt industry has looked at a large number of bitumen modifiers<sup>9</sup> including sulphur, natural and synthetic rubbers and a wide variety of polymers. The IntegraBase modifier can improve the workability of an asphalt mixture because the petroleum fluxing oil which it contains has a mild softening effect on the bitumen to which it is added.

## **Pavement Thickness Reduction Analysis**

### **Objective**

The objective of this analysis is to determine the thickness of an un-modified hot mixed asphalt (HMA) layer required to produce an equivalent performance to a pavement with 8 inches IntegraBase-modified HMA layer.

### **Assumptions used in analysis:**

- The pavement consists of a two-layer system: HMA layer over a granular subgrade
- The granular subgrade has a representative modulus of 10,000 psi
- The loading vehicle consists of a single axle truck with 18,000 pounds per single axle
- The single axle consists of dual tires inflated at 100 psi

### **Modulus Testing Data**

The modulus of the IntegraBase-modified and un-modified HMA layers were obtained from the laboratory data generated on HMA mixtures produced with asphalt binders sourced in the Middle East, with and without the IntegraBase modifier. The following resilient modulus properties of the un-modified and IntegraBase-modified HMA mixtures were used:

	<u>Un-modified HMA</u>	<u>IntegraBase-modified HMA</u>
Resilient Modulus at 77°F, psi	520,000	580,000
Resilient Modulus at 104°F, psi	120,000	245,000

### **Analysis Process**

The pavement analysis considered fatigue cracking and rutting failures. The following steps summarize the analysis process:

- Predict the fatigue and rutting performance of a pavement constructed with 8 inches IntegraBase-modified HMA layer over the subgrade.
- Predict the fatigue and rutting performance of a pavement constructed with 8 inches un-modified HMA layer over the subgrade.
- Compare the fatigue and rutting performance of the IntegraBase-modified and un-modified pavements.
- Estimate the thickness of the un-modified HMA layer necessary to achieve the same fatigue and rutting performance provided by the IntegraBase-modified pavement.

### **Fatigue Analysis**

This analysis used the Asphalt Institute model to predict the fatigue performance of the IntegraBase-modified and un-modified pavements:

$$N_f = 0.0796 * (\epsilon_t)^{-3.291} * (E)^{-0.854}$$

Where:

$N_f$  = Number of load repetitions to fatigue failure

$\epsilon_t$  = Tensile strain at the bottom of HMA layer (in/in)

$E$  = Modulus of the HMA layer (psi)

Fatigue cracking is predominant at intermediate temperatures. Therefore, the resilient modulus at 77°F were used to represent the properties of the IntegraBase-modified and un-modified HMA layers. Using the resilient modulus of the IntegraBase-modified and un-modified HMA layers and the resilient modulus

of the subgrade at 10,000 psi in the multi-layer elastic solution, led to the determination of the tensile strains at the bottom of the HMA layers at various thicknesses. Using the determined strains in the fatigue performance model led to the determination of the number of load repetitions to fatigue failures.

<u>HMA Type</u>	<u><math>\epsilon_t</math> (in/in)</u>	<u><math>N_f</math></u>
8" IntegraBase-Modified	$250 \times 10^{-6}$	1,420,000
8" un-modified	$397 \times 10^{-6}$	571,000
9" un-modified	$342 \times 10^{-6}$	933,000
10" un-modified	$302 \times 10^{-6}$	1,404,000

The above data show that the un-modified HMA layer would have to be 10 inches thick in order to achieve the same fatigue performance as the 8 inches thick IntegraBase-modified HMA layer.

### ***Rutting Analysis***

Rutting of HMA pavements can be generated from two sources: a) the subgrade layer and b) the HMA layer. Each source has its unique contributing factors and methods of control. The following presents the analysis of the two types of rutting.

#### *Rutting from the Subgrade:*

This portion of the analysis assumes that the HMA and base layers are well designed and they will not contribute to the surface rutting of the pavement. Any surface rutting is therefore, generated by the excessive compressibility of the subgrade layer. This analysis evaluated the ability of the IntegraBase-modified and un-modified HMA layers in protecting the subgrade from excessive rutting. The following Asphalt Institute rutting performance model was used to conduct the rutting analysis:

$$N_d = 1.365 \times 10^{-9} (\epsilon_v)^{-4.477}$$

Where:

$N_d$  = number of load repetition to rutting failure

$\epsilon_v$  = vertical compressive strain on top of the subgrade (in/in)

Rutting of HMA pavements is predominant at high temperatures. Therefore, the resilient modulus at 104°F were used to represent the properties of the IntegraBase-modified and un-modified HMA layers. Using the resilient modulus of the IntegraBase-modified and un-modified HMA layers and the resilient modulus of the subgrade at 10,000 psi in the multi-layer elastic solution, led to the determination of the vertical compressive strains at the top of the subgrade layer at various thicknesses. Using the determined strains in the rutting performance model led to the determination of the number of load repetitions to rutting failures.

<u>HMA Type</u>	<u><math>\epsilon_t</math> (in/in)</u>	<u><math>N_f</math></u>
8" IntegraBase-Modified	$640 \times 10^{-6}$	271,500
8" un-modified	$955 \times 10^{-6}$	45,250
9" un-modified	$806 \times 10^{-6}$	96,700
10" un-modified	$690 \times 10^{-6}$	193,900
10.5" un-modified	$647 \times 10^{-6}$	259,000

The above data show that the un-modified HMA layer would have to be 10.5 inches thick in order to achieve the same rutting performance as the 8 inches thick IntegraBase-modified HMA layer.

#### *Rutting in the HMA Layer:*

The latest development in predicting the rutting within the HMA layer calls for the determination of the plastic vertical compressive strain within the HMA layer. The total rutting within the HMA layer is then calculated by multiplying the permanent strain times the thickness of the HMA layer. The following relationship is the most commonly used to predict rutting in the HMA layer.

$$\varepsilon_p = \varepsilon_r [(1.781 \times 10^{-4}) (N)^{0.4262} (T)^{2.028}]$$

$$RD_{HMA} = \varepsilon_p \times H_{HMA}$$

Where:

$\varepsilon_p$  = Permanent strain within the HMA layer (in/in)

$\varepsilon_r$  = Elastic strain within the HMA layer (in/in)

N = Number of load repetitions

T = Temperature of the HMA layer (F)

$RD_{HMA}$  = Rutting generated in the HMA layer (in)

$H_{HMA}$  = Thickness of the HMA layer (in)

The temperature at which the pavement starts becoming highly susceptible to rutting in the HMA layer is around 104°F. Using the resilient modulus property of the IntegraBase-modified HMA and un-modified HMA at 245,000 and 120,000 psi, respectively, one can evaluate the resilient strain and permanent strains within the HMA layer. A process similar to the one used to predict the necessary thickness of the un-modified HMA layer to protect the pavement from subgrade rutting could be used to predict the necessary thickness to limit the HMA rutting. However, since the rutting in the HMA layer is directly related to the thickness of the HMA layer and due to the significant increase in the modulus of the IntegraBase-modified HMA mix relative to the un-modified HMA mix, it can be concluded that the increase in the thickness will not be able to overcome the low modulus of the un-modified HMA mix. In other words the equivalent layer of the un-modified HMA mix will have to be extremely thick (i.e in excess of 20 inches) to overcome the significant reduction in the modulus of the un-modified HMA mix.

It should be noted that the number of load repetitions to fatigue cracking and rutting failures predicted by the performance models are only applicable for comparative purposes and they should not be construed as the actual traffic loading repetitions in the field.

## **Commercial History of IntegraBase**

The IntegraBase modifier was first introduced on a commercial basis under the name IntegraBase in Denmark in 1980. Since that time, hundreds of IntegraBase pavement applications have been constructed in Europe, Asia, the United States, Mexico and South America.

IntegraBase modified bitumen has been used in the construction of base courses, binder and levelling courses, wear courses and chip seals. It was discovered in early tests that IntegraBase is not suitable for

use in wear courses. Since the IntegraBase catalyst utilizes oxygen as one of the driving forces of the reaction, if treated asphalt is continuously exposed to Oxygen, the reaction will continue. This is not optimal for wear courses, and the reason that IntegraBase is only used in base or binder courses, where the oxygen exposure is cut off.

The favorable performance of pavements using IntegraBase have caused the use of IntegraBase asphalt to be specified as an acceptable alternative pavement construction technique by different countries around the globe, with many currently testing and considering the technology for use.

In the past 5 years, IntegraBase has completed numerous successful projects and field tests around the world. Caltrans is currently evaluating the IntegraBase technology to eventually build a specification for high strength asphalt concrete bases. The Port of Oakland completed a successful test of IntegraBase in their Gantry Crane runways, where the IntegraBase sections showed no rutting compared to the 4" of rutting in the unmodified sections.

IntegraBase was also used in the construction of the 389km highway from Kabul to Kandahar, which was funded by USAID and constructed by 3 different contractors managed by the Louis Berger Group. IntegraBase enabled Louis Berger to reduce the thickness of the base course from 14-inches to 8-inches, allowed for the reduction of a 12-inch crushed gravel sub-base, as well as the ability to use river-run gravel rather than the planned use of crushed aggregate. In all, the use of IntegraBase saved USAID over \$90 Million – and enabled them to build the road in less than one year.

#### SUMMARY

IntegraBase is a catalytic additive to bitumen which chemically reacts with the asphalt mix to permanently modify and improve the properties of asphalts. The IntegraBase modified asphalts have higher durability, strength and potential life than unmodified asphalts and can be used with inferior aggregates and with sand to produce asphalts equal to or superior to normal asphalts with well graded quality aggregates.

IntegraBase modified asphalts have high rutting resistance at high temperatures and flexure at low temperatures. Other properties of IntegraBase modified asphalts are: improved anti-stripping characteristics, improved workability, reduced oxidation aging, and the ability to have reduced pavement thickness with the same properties as a full service pavement. IntegraBase modified asphalt pavements are in use in Europe, the United States of America, the Middle East and Asia. IntegraBase technology is currently being tested in countries in Asia, Europe, and Latin America.

# *Resperion Whitepaper*

## **INDEX OF REFERENCES**

1. Perkins, James D. "Laboratory Evaluation of IntegraBase Processed Asphalt for Use with Marginal Construction Material", U.S. Corp of Engineers, 1981.
2. Nunn, M.E., Powell, W.D., Co1wi11, D.M. "Theoretical Assessment of the Contribution of IntegraBase Binder to the Performance of Road Pavements", TRRL Memorandum MM131, 1986.
3. Daines, M.E., Carswell J., Co1wi11, D.M. "Assessment of 'IntegraBase' as an Additive for Binders for Wearing Courses and Road Bases". Department of Transport TRRL- RR54, 1985.
4. Laboratory Evaluation Of IntegraBase Modifier for Use in Bituminous Binder Course; Central Road Research Institute (CRRl); New Delhi, India; July 2005
5. Peter Sebaaly, Ph.D."Chemcrete-Modified Asphalt Mixtures." University of Nevada Reno, January 2001