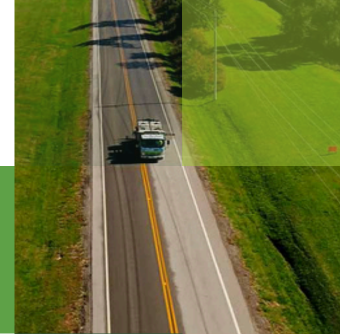

RePlay™

ADVANCING SUSTAINABLE PAVEMENT PRESERVATION – A TECHNICAL ANALYSIS

BY SHATEC ENGINEERING CONSULTANTS, SPONSORED BY BIOSPAN

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Contents

EXECUTIVE SUMMARY

"Petroleum-based sealers and rejuvenators are used with various degrees of success, but they all raise environmental concerns. RePlay offers an effective alternative to using petroleum-based products from both economical and environmental standpoints."

- Dr. Shakir Shatnawi, PhD, PE, President of Shatek Engineering Consultants

Oxidative Aging as a Primary Cause of Asphalt Distress: The analysis emphasizes that the oxidation of the asphalt binder is a major contributor to non-load associated distresses like cracking (block, longitudinal, transverse), raveling, and weathering. This hardening and embrittlement of the asphalt concrete leads to premature failure and necessitates costly rehabilitation or reconstruction.

Pavement Preservation as a Cost-Effective Strategy: The white paper advocates for early-stage pavement preservation treatments to control non-load associated distresses and delay the need for more extensive and expensive repairs.

RePlay® as a Bio-Based Solution for Rejuvenation and Sealing: The paper introduces RePlay as a soybean-based, environmentally friendly alternative to traditional petroleum-based sealers and rejuvenators. It highlights RePlay's ability to not only seal the pavement surface but also penetrate and restore the chemical properties of the aged asphalt binder.

"[RePlay as] an effective rejuvenator not only seals against air, water and chemical contaminants and penetrates the asphalt concrete, but it can also chemically revitalize its asphalt binder through replacing lost oils with polymers to restore the binder's desirable properties that have been lost by oxidation."

Demonstrated Effectiveness Through Field and Laboratory Studies: The white paper presents various studies examining RePlay's impact on skid resistance, water runoff, pavement texture, permeability, polymer penetration, mechanical properties, binder rheology, and cracking resistance.

Important Ideas and Facts Supported by Evidence:

Skid Resistance: Field studies in Ohio and New York, and testing at Tyndall Air Force Base in Florida, indicated that RePlay application did not significantly reduce skid resistance and in some cases appeared to maintain it.

Water Runoff: Visual observations in Hutchinson indicated that RePlay treatment altered water behavior, suggesting reduced permeability and increased wicking in untreated sections.

Pavement Texture: Laboratory studies using the Sand Patch test (ASTM E965) in Canada and Florida showed a reduction in Mean Texture Depth (MTD) after RePlay treatment, indicating a filling of surface voids.

Results showed MTD reductions of 8% and 25% in Canada and between 19.5% and 26% in Florida. The paper states, "This indicates that the penetration of RePlay into the surface pores has closed the surface significantly; thus, providing for a barrier to air, water, chemical contaminants, and de-icing salt intrusion into the voids within the pavement."

Pavement Permeability: Water absorption testing on asphalt cores from Edmonton, Canada, demonstrated a significant reduction in water absorption in RePlay-treated samples compared to untreated controls.

"The untreated samples absorbed as much as 10 times the amount of water absorbed by the samples treated with RePlay." This suggests RePlay effectively seals the pore structure, reducing water damage.

Polymers Penetration: FT-IR spectroscopy analysis on New York pavement samples confirmed the penetration of polymers (SBS and SBBS) from RePlay into the asphalt mixture, reaching depths of 0.75" to 1.25" and even up to 1.75" in some cases.

Mechanical Properties: Laboratory tests on core samples showed improvements in several mechanical properties after RePlay treatment.

Increased penetration and decreased softening point of recovered bitumen, suggesting improved binder performance.

RePlay Effect on Rheological Properties of In-Service Asphalt: Testing on recovered binders from a one-year-old overlay showed that RePlay-treated binders exhibited rheological properties closer to unaged binders compared to untreated binders, suggesting it retards oxidative aging.

Cracking Resistance: Texas Overlay Testing indicated that while both treated and untreated mixes showed "good" cracking performance based on CRI-Gf interaction, the RePlay-treated mixes exhibited slightly better performance.

Chemical Analysis: Analysis of recovered binders showed a lower asphaltene fraction and Carbonyl Index (CI) in RePlay-treated specimens compared to untreated ones, further supporting the claim of aging retardation.

Low Temperature Cracking: Bending Beam Rheometer (BBR) testing suggested that RePlay treatment could improve the low-temperature cracking resistance by potentially lowering the creep stiffness and maintaining or improving the m-value of the asphalt binder.

Construction with RePlay: The white paper describes the application process as relatively simple, requiring limited mobilization and construction time, and using standard equipment like bituminous distributors or sprayers.

"Normally, one lane-mile of pavement requires ~2 hours for a two-person crew to spray and apply RePlay."

Environmental and Safety Benefits: RePlay is highlighted as an environmentally friendly and sustainable product due to its bio-based composition (88% agricultural-based, 40% soybean oil), petroleum-free nature, potential carbon-negative footprint, and non-toxic properties. It is also reported to have no odor or oil tracking once cured and is safe for people, pets, and foliage.

Generic Specification: The paper includes a sample generic specification for projects using RePlay, outlining material requirements, application procedures, and performance expectations.

Conclusion:

The analysis presents a comprehensive overview of the benefits and effectiveness of BioSpan's RePlay® as a pavement preservation treatment. Drawing upon a range of field and laboratory studies, the paper provides evidence that RePlay can penetrate aged asphalt, rejuvenate the binder by adding new polymers, seal the pavement against water and air intrusion, improve mechanical properties and cracking resistance, and retard oxidative aging. Furthermore, it emphasizes the environmental advantages and ease of application associated with this bio-based product. The information presented strongly suggests that RePlay offers a viable and sustainable approach to extending the service life of asphalt pavements and reducing the need for costly reconstruction.

ABOUT THE AUTHOR

Dr. Shakir Shatnawi is a registered professional engineer in California. He is a former California Department of Transportation (Caltrans) State Pavement Engineer and he is currently the president of Shatec Engineering Consultants, LLC where he directs the engineering operations, performs pavement studies/investigations and training. He has over 29 years of professional engineering experience encompassing public agencies (FHWA & Caltrans), academia and industry with over 200 technical publications.

Throughout his career, Dr. Shatnawi served as a principal investigator on multi-million dollar pavement projects. He was the QC/QA program manager, the chief of Pavement Research, the chief of Pavement Design and Rehabilitation and the chief of Pavement Preservation, and served as the Caltrans State Pavement Engineer. He directed Caltrans' Pavement Program as a Division Chief and oversaw over 50,000 lane miles with a budget of over $200 million in pavement preservation and over $500 million in pavement rehabilitation.

Shakir received his Ph.D. in civil engineering (Pavement Engineering specialty) from the University of

Arkansas (1990), and received his M.S. in civil engineering (Construction Management specialty) from San Jose State University (1985), and B.S. degree in Civil Engineering from California State University, Sacramento (1982).

Dr. Shatnawi's education and experience demonstrate a wealth of engineering knowledge in pavement analysis, design, rehabilitation, materials and construction in asphalt, concrete, soils, earth structures and foundations. As an expert orator, Dr. Shatnawi frequently shares his knowledge at major conferences and through publications. As a recipient of many acknowledgements from the government and industry, Dr. Shatnawi has an impeccable reputation for his significant professional contributions. The following are some of his awards and acknowledgments:

- Received the Leadership in Transportation and Quality Pavements Award from the California Asphalt Pavement Association in 2010.
- Received the Industry Individual of the Year Award in 2008 for outstanding contributions to pavement preservation activities in California.
- Received the Caltrans Director's Superior Accomplishment Award in 2006 for outstanding accomplishments in pavement preservation.
- Received the Caltrans Director's Innovation Award in 2004 for outstanding contribution to pavement warranties.

- Received the Caltrans District 7 Excellence in Transportation Award in 2003 for outstanding contribution to the first long life rigid pavement project on I-10 near Pomona and the successful use of fast-setting hydraulic cement and dowel bar retrofit.
- Received the Industry Long Life Pavement Award of Excellence in 1999 for outstanding contribution to the 710 long life flexible pavement projects.
- Received the American Society of Civil Engineers' Award in 1999 for outstanding service as Education Chairman for the years 1997 through 1999.
- Received the FHWA Dwight Eisenhower

Transportation Research Fellowship, 19891990.

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About ***Shatec***

Shatec Engineering Consultants specializes in pavement engineering services. Based in Sacramento, California, the firm focuses on providing pavement management solutions to public agencies and private entities. Their consulting services encompass all aspects of pavement engineering, including system assessment, planning, programming, design, construction management, quality control and assurance, maintenance and preservation.

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INTRODUCTION

Two categories of distresses affect asphalt concrete pavement: load-associated and non-load associated distresses[1]. The non-load associated distresses result from climatic exposure, oxidation, temperature changes, and possibly from poor materials or construction methods.

As the name implies, these distresses occur without the presence of traffic, though traffic loading can dramatically increase their severity. Asphalt binder oxidation and the age hardening of the asphalt concrete are a major cause of most distress. The binder stiffness and viscosity increase due to hardening and the flexibility resistance within the pavement will be lost. Most common among non-load associated distresses are block cracking, longitudinal and transverse cracking, and raveling and weathering[2].

Block cracking forms interconnected cracks that divide pavement surfaces into rectangular segments. It is driven by volume change in the asphalt concrete induced by daily temperature cycling.

Longitudinal cracks are parallel to the pavement center line and usually occur due to shrinkage of the asphalt concrete pavement caused by low temperatures or age-hardening of the asphalt binder. They may also occur due to reflection cracking from cracks beneath the asphalt course.

Transverse cracks occur across the pavement width and are caused by low temperature or age hardening. Like longitudinal cracks, they can also occur by reflection cracks.

Raveling is the wearing away of the pavement surface due to the dislodgement of aggregate particles and loss of asphalt binder. This distress is primarily caused by the age-hardening of the asphalt binder.

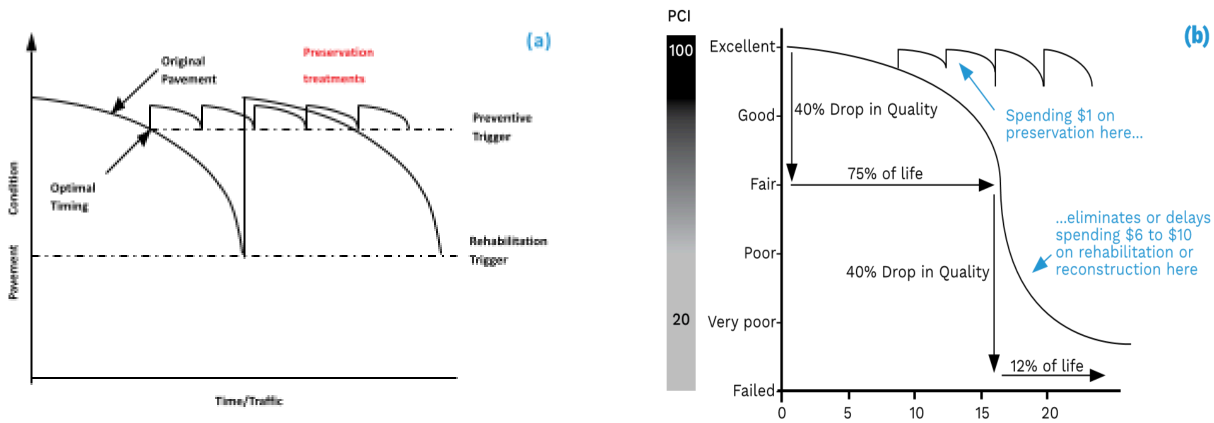
The most effective approach to avoiding or minimizing the severity of non-load associated distresses is through establishing AND aggressively funding a proactive pavement preservation program. It can employ preventive maintenance methods including surface treatments, crack sealing, thin overlays, etc.

A typical pavement preservation program applies the right treatment at the right time and the right place before damage becomes excessive and costly.

[1] Huang 2003
[2] Huang 2003

Where a relatively inexpensive treatment applied to the pavement before condition deteriorates can extend the life of the pavement[3] in as much the same way as a more serious and significantly costlier rehabilitation applied later. Further, a well-planned preservation program can result in substantial savings for the agency[4]. Spending one dollar on pavement preservation treatment applied at the right time before the asphalt starts to deteriorate, can eliminate, or postpone the need to spend 6-10 times or more on serious and expensive rehabilitation or reconstruction.

Figure 1. Pavement preservation concept (a) Preservation versus rehabilitation, and (b) an example of saving that can be achieved by implementing an effective preservation program.



[3] Figure 1a, Galehouse et al. 2006
[4] Figure 1b, Galehouse et al. 2006

At early stages, non-load associated distresses can be effectively controlled through preservation or maintenance treatments. Oxidative age-hardening of the asphalt binder is considered the primary cause of non-load associated distresses. Therefore, pavement preservation treatments must be selected such that they can delay that oxidative aging process. They may reduce the pavement surface permeability to restrict the oxygen supply to the pavement and protect the pavement from associated moisture damage.

Relevant preservation treatments that seal the pavement surface against air and water intrusion include fog seals, topical pavement sealers, slurry seals, micro-surfacing, ultrathin bonding wearing courses, chip seals, etc.[5] These treatments can vary greatly both in their effectiveness and cost depending on the existing pavement surface condition, available materials, and timing.

At an early stage, topical seals such as fog seals can be both effective and low-cost. As the pavement surface condition deteriorates, more aggressive treatments become necessary.

In the remainder of this paper, the oxidative aging of the asphalt pavement and preservation/ maintenance treatments to stop or reverse the oxidation damage of asphalt will be discussed, along with the effectiveness of BioSpan's RePlay®, a bio-based environmentally friendly rejuvenator and sealer.

[5] MTAG, 2008

OXIDATION DAMAGE OF ASPHALT

The oxidation of the asphalt binder, also called oxidative aging, in an asphalt concrete pavement is a major contributor to its premature failure. This is due to hardening or stiffening of the asphalt concrete rendering it more susceptible to excessive fatigue cracking under repeated traffic loading. The direct exposure of the asphalt pavement to ultraviolet (UV) radiation from the sun, as well as air and water, are principal causes of asphalt binder oxidation.

Oxidation damages the asphalt bitumen—mainly the oily resinous component of the bitumen's hydrocarbon molecules—and the loss of its desirable characteristics. This starts to occur immediately from the time the asphalt concrete is placed. The loss of the bitumen's desirable characteristics increases its viscosity and decreases its ductility resulting in hardening and embrittlement of the asphalt concrete. Cracks will start to occur in the asphalt concrete under traffic, allowing air and water into the asphalt and further deterioration of the bitumen characteristics.

The presence of moisture in the voids of the asphalt concrete mixture also increases its oxidation rate[6]. In the presence of moisture at the surface of the asphalt binder, the oxidation rate is estimated to increase by around 25 percent[7]. With hardening of the asphalt concrete, the fines are gradually lost from the mix leading to additional deterioration or potential "shattering" of the pavement.

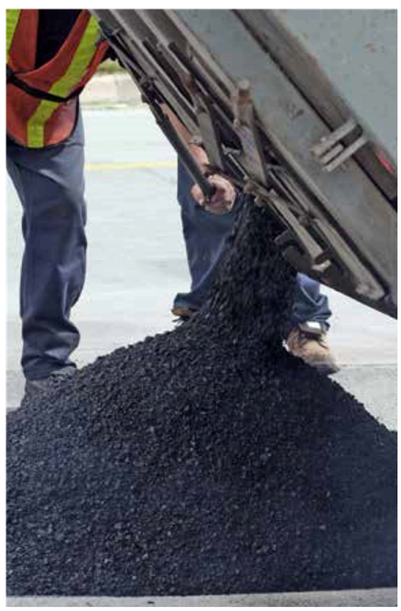
The hardening or stiffening (loss of ductility) of asphalt concrete due to oxidation reduces its important ability to react to inevitable temperature fluctuations. The rate of oxidation (age hardening) of the asphalt increases as the temperature in the pavement increases. Therefore, hardening is most severe at the pavement surface where temperatures are highest during summer. Besides temperature, the damaging UV rays in the solar radiation catalyze oxidation of the asphalt binder resulting in additional hardening and damage to its ductile properties[8].

[6] Huang et al. 2007, Hanson et al. 2009
[7] Hanson et al. 2009
[8] Hanson et al. 2009

Mixture variables such as binder type (through its asphalt chemistry) and mix volumetric properties can affect the oxidation rate. Some binders may oxidize at a faster rate than others, and water absorptive aggregates can result in greater loss of flexibility (ductility) of the binder used. The number of interconnected voids in the asphalt mixture greatly affects oxygen and water movement (permeability) in the mix; thus influencing the hardening rate of the asphalt binder deep into the top lift.

With the reuse of oxidized asphalt pavement into new pavement, the oxidation issue is potentiated due to the pavement structural weakness caused by the introduction of the reclaimed asphalt pavement (RAP). Finally, as oxidative aging continues to damage the pavement surface, water penetrates easier down into the pavement structure softening the lower unbound base, subbase, and subgrade materials which can result in severe structural damage (foundation failure) which could trigger the need for major rehabilitation or reconstruction.

As can be seen, a simple (but inevitable) mechanism such as oxidation can evidently lead to excessive cost of pavement repair. Luckily, there are relatively inexpensive treatments that can be employed as preventive maintenance measures to reduce or even reverse the impact of oxidation on asphalt pavements in their early age of service (before irreversible damage occurs); thus, overcoming the need for the substantially higher costs of rehabilitation repairs or reconstruction.



SURFACE TREATMENT

The oxidation of asphalt concrete is most severe in the first 2-4 years after placement[9]. As mentioned previously, oxidation aging occurs first at the pavement surface due to the high temperature and exposure to the damaging effect of UV rays, water, and air. Therefore, to protect the pavement structure, this accelerated aging process must be confined to the pavement surface.

This may be effectively achieved by the periodic application of sealers and rejuvenators; a preventive maintenance measure that is considered the most common and inexpensive method for halting, and sometimes reversing, the oxidation process. Different types of materials have been used to different degrees of effectiveness, including emulsified sealers, asphalt binders, and formulated rejuvenators.

Pavement rejuvenators are products designed to restore asphalt binder flexibility in an existing asphalt concrete pavement that has undergone oxidation, while simultaneously stopping the loss of fines from the mix and sealing the surface against penetration by water, air, and chemical contaminants.

Pavement rejuvenators are applied by spraying the rejuvenation material to the existing aged, oxidized asphalt pavement to restore asphalt concrete ductility besides improving other features. Therefore, the application of pavement rejuvenators can be an effective low-cost technology to slow or reverse the damaging effect of oxidation; thus, extending the remaining service life of the pavement.

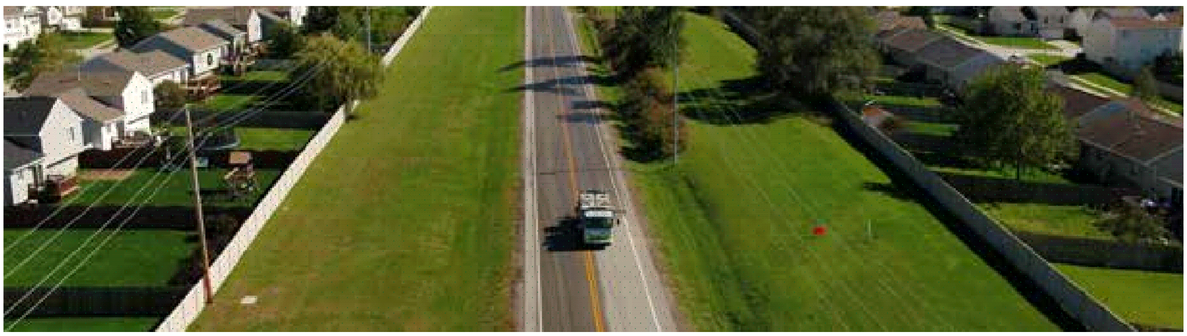
Most rejuvenators are formulated with oils that are selected that can penetrate the asphalt pavement layer through its pore structure to improve the asphalt binder properties that were lost by oxidation. The oils used in formulating the rejuvenator must be selected or designed to replenish the oily fraction of the asphalt binder present in the mix. The most used traditional emulsified sealers and asphalt binders are those that have been manufactured from petroleum products.

In recent years, environmentally friendly (green) rejuvenators and sealers have been introduced in the market and are currently finding wide acceptance worldwide as

[9] Kuennen 2006

sustainable alternatives to traditional products. RePlay is an agricultural oil seal and rejuvenation agent that has proved, both in the laboratory and field, to be a cost-effective and efficient preventive maintenance treatment for asphalt pavements since its introduction in the United States in 2003. Here we will discuss detailed information on the benefits of using RePlay as a green technology rejuvenator and sealer in asphalt pavement maintenance with detailed laboratory and field performance studies on the impact of using RePlay presented.

REPLAY



Petroleum-based sealers and rejuvenators have traditionally been the standard materials attempted for preserving asphalt pavements against oxidative aging. Rejuvenators refer to the class of products designed to restore asphalt binder flexibility. Besides sealing the pavement, rejuvenators are capable – to variable degrees – of restoring the chemical properties lost by deterioration of the asphalt binder from the moment the asphalt concrete was placed. An effective rejuvenator not only seals against air, water and chemical contaminants and penetrates the asphalt concrete, but it can also chemically revitalize its asphalt binder through replacing lost oils with polymers to restore the binder's desirable properties that have been lost by oxidation.

In 2001, BioSpan Technologies, Inc. developed and patented a soybean-based sealant and rejuvenator product called RePlay. It acts as a "green" alternative to petroleum-based topical sealants and rejuvenators and was introduced to the United States market in 2003.

RePlay is 88% bio-based rejuvenator; of which 40% is derived from soybean oil[10]. The remainder 12% of the RePlay composition is recycled materials; particularly polystyrene, that is especially used in the formulation of RePlay to impart essential polymers to the asphalt binder[11].

RePlay rejuvenates the asphalt via reversing the oxidation process by adding new Superpave polymers; namely Styrene-Butadiene-Styrene (SBS) and

[10] Kindler 2009
[11] Levy 2012

Styrene-Butadiene-Butadiene-Styrene (SBBS). Both are known to be effective in strengthening and increasing the durability of the asphalt binder which improves the asphalt concrete resistance to raveling, rutting, and cracking. Five additional new polymers made from soy and other bio-based components further strengthen the asphalt binder material.

Because RePlay is a petroleum-free product and made with recycled materials, it is both non-harmful to the environment and a sustainable product, which also reduces dependence on and increasing prices of foreign oil. Whereas many petroleum-based rejuvenators may possess some of the attributes that RePlay has, they are not ecologically friendly and sustainable products, and may reduce the pavement surface skid resistance.

RePlay Benefits

The use of RePlay rejuvenator and oil sealer on asphalt concrete-surfaced pavements offers myriad benefits that can be grouped into several areas impacting the pavement, environment, and users.

Some of the benefits that have been reported in the technical literature include:

1. Renewing aged asphalt pavement that has hardened and become brittle.
2. Softening the stiffness (hardness) of the oxidized asphalt pavement surface, making it less brittle, restoring its flexibility, slowing its rate of aging and oxidation, and extending its service life.
3. Reducing viscosity of the asphalt binder and modifies its rheological properties.
4. Reducing the binder brittleness and reducing the PG low temperature grade of the asphalt binder in low temperature (freezing) conditions.
5. Sealing the disintegrated asphalt surfaces and halting further raveling and loss of fines from the aggregate matrix.
6. Sealing the pavement surface and hairline cracks; thus, decreasing pavement permeability to water (by up to 95%).
7. Sealing the pavement against harmful chemical contaminants and deicing salt penetration.
8. Rejuvenating asphalt binder in asphalt mix by adding new SBS and SBBS, and five additional polymers (at least 15%).
9. Tightening and adding density to the existing asphalt binder; thus, improving its resistance against UV damage.
10. Increasing the service life of a treated road surface by 2-3 times its untreated useful life span. A single application of RePlay on the right pavement at the right time has been reported to add up to 5 years to the pavement service life.
11. Offering an inexpensive topical treatment method to extend pavement life and delay major maintenance and rehabilitation works. If RePlay is applied in a preservation mode, an agency can achieve a long-term cost saving of several hundred percent compared to the cost of traditional asphalt overlays.

Additionally, RePlay offers the following advantages that are not typically offered by traditional petroleum-based rejuvenators and sealers:

1. It has low viscosity enabling it to flow easily into cracks and surface voids to seal them. It can penetrate a depth of 0.75” to 1.25” (and up to 1.75”) within the asphalt layer in minutes.
2. It increases or at least maintains skid resistance of asphalt pavement.
3. It requires limited mobilization and construction time.
4. It does not have odor, or any oil tracking once cured.
5. It is safe around people, pets, and foliage.
6. It quickly absorbs, sets, and cures within 15-30 minutes after placement; thus, reducing the duration of the lane or facility closure to traffic (vehicular and foot). It also does not require sand blotting; and as such it provides for lower maintenance costs.
7. It strongly bonds to the asphalt matrix; thus, no residual runoff or discharge may occur immediately after a rain or over time.
8. It is 88% agricultural-based, with 40% made from soybean oil; thus, it is eco-friendly and a completely non-toxic product.
9. It has a “carbon negative footprint”; thus, it removes harmful greenhouse gases in the surrounding environment.
10. It makes use of nanoparticle bio-based polymers to effectively attach to the binder.
11. It provides for a more aesthetically appealing pavement surface.
12. It is virtually clear and will not harm pavement delineation. No re-striping is necessary after application unless pavement striping is already deteriorated and needs to be replaced. It has been found to increase marking conspicuity and extend their service life. Also, while RePlay slightly darkens lines, it does not alter the reflectivity of reflective beads.
13. Generally, it is not as temperature-sensitive as bitumen-based products; therefore, it can be applied nearly year-round.

RePlay is Bio-based Technology

RePlay applied to the left lane of the road

Pavement agencies continue to strive for employing sustainable practices that reduce the stress on the environment. Several programs (e.g., LEED and Greenroad) have been developed to rate and certify technologies used in the construction, preservation, maintenance, and rehabilitation of roadway and highway pavements in regard to their ability to support sustainable pavement solutions[12].

RePlay is considered a green asphalt preservation treatment, and the rejuvenation with RePlay is considered a sustainable technology for reasons owing to both the rejuvenation process and the product, among which:

1. Rejuvenation process is relatively low-cost technology that revitalizes the existing pavement on-site without the need to remove and transport existing materials; thus, minimizing traffic congestion and air pollution.
2. RePlay as the rejuvenator agent and sealer is polymer-enhanced soybean oil (88% bio-based), and therefore an environmentally-friendly product. Most of the polymers in RePlay's formulation are derived from recycled material (polystyrene) coupled with the bio-based materials in the formulation.

The environmental impact of RePlay from the point of its manufacturing to its application on the pavement and eventual breakdown into the environment was assessed with BEES[13]; a Building for Environmental and Economic Sustainability software developed by the U.S. National Institute for Standards and Technology and uses the concepts of life-cycle analysis, LCA[14]. This study compared the environmental impact of RePlay against a traditional petroleum-based alternative called Reclamite, which is an emulsion made of specific petroleum oils and resins.

[12] Cleaver 2003
[13] Lippiatt 2011
[14] Levy 2012, BioSpan 2009

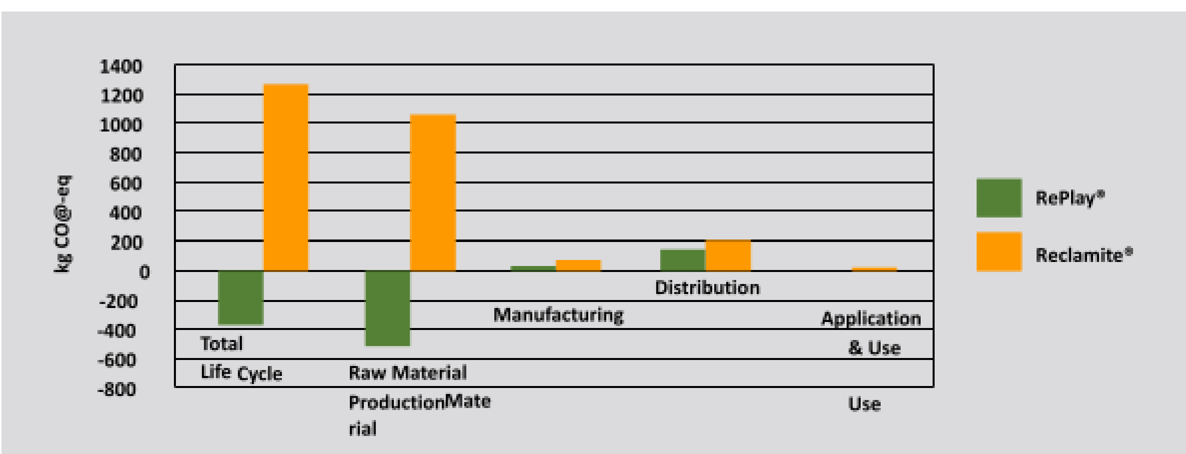
The comparison considered all the stages in the life of the two products including: (i) acquisition of raw material, (ii) manufacturing, (iii) transportation, (iv) installation, (v) use, and (vi) recycling and waste management[15]. The results of the analysis indicated that the petroleum-based product increased the amount of carbon dioxide (CO2) in the environment; thus increasing the global warming potential, and required a greater amount of fuel energy during its life cycle compared to RePlay.

In fact, the use of the agricultural soybean-based RePlay as a rejuvenator/sealer for asphalt concrete surfaced facilities was found to reduce the amount of CO2 already present in the atmosphere because (i) no CO2 is produced during manufacturing, and (ii) growing the agricultural material used in making the product (i.e., soybean plants) consumes CO2 from the atmosphere. The equivalent amount of CO2 produced and released to the environment during the life cycle of the two compared products in the various phases was considered in the analysis[16].

As shown in Figure 2, the amount of equivalent CO2 added to the environment during the life cycle of Reclamite was over 1200 kg, whereas RePlay removed about 400 kg of equivalent CO2. Therefore, RePlay has a carbon negative footprint. The amount of CO2 depleted from the environment during the production of the agricultural material (soybeans) was found to easily offset the amount of CO2 added during the manufacturing, transportation, and application of RePlay[17]. Additionally, raw material (soybean plant) returns nitrogen to the soil; thus, requiring less or no fertilizers, which are petroleum-based, to grow crops.

Finally, because RePlay is an agricultural–based product – unlike petroleum-based products – it is safer to users during application.

Figure 2. Global warming potential in terms of equivalent CO2 added or removed during all phase of production and use of RePlay vs. Reclamite



[15] Levy 2012
[16] Figure 2, BioSpan 2008
[17] Levy 2012, BioSpan 2012

FIELD PERFORMANCE STUDIES

Skid Resistance

Skid resistance, in terms of friction number FN40, was measured on asphalt pavement sections on State Route 119 in Ohio between PM 2.70 and 3.05[18]. Table 1 shows results of testing before treatment (the top two sets of data) and at various times after application: 19 and 69 minutes for eastbound direction and 28 and 60 minutes for westbound direction.

As can be seen in Table 1, skid numbers measured indicated that the application of RePlay did not negatively impact skid resistance of the tested pavement surfaces.

[18] BioSpan 2010

Table 1. Skid resistance of state route 119 in Ohio before and after treatment with RePlay

SKID TEST DATA

	RUN 1		RUN 2					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Eastbound	2.79	46.5	2.80	47.1	46.8	0.6	47.1	46.5
	2.85	49.5	2.85	48.3	48.9	1.2	49.5	48.3
	2.91	44.9	2.90	44.2	44.5	0.7	44.9	44.2
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Westbound	2.82	41.8	2.81	46.3	44.1	4.4	46.3	41.8
	2.87	44.6	2.87	43.1	43.8	1.5	44.6	43.1
	2.94	44.2	2.95	45.0	44.6	0.8	45.0	44.2
	19 min. after		25 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Eastbound	2.80	46.5	2.80	46.2	46.3	0.3	46.5	46.2
	2.86	41.1	2.86	44.4	42.7	3.2	44.4	41.1
	2.92	46.4	2.92	44.7	45.5	1.7	46.4	44.2
	69 min. after		75 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
	2.82	44.7	2.82	43.9	44.3	0.8	44.7	43.9
	2.87	42.4	2.87	43.3	42.9	0.8	43.3	42.4
	2.93	43.6	2.93	44.5	44.0	0.9	44.5	43.6
	28 min. after		33 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Westbound	2.81	43.7	2.81	41.6	42.6	2.0	43.7	41.6
	2.88	35.7	2.89	37.8	36.7	2.1	37.8	35.7
	2.95	43.0	2.95	43.4	43.2	0.4	43.4	43.0
	60 min. after		70 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
	2.82	42.7	2.80	45.1	43.9	2.3	45.1	42.7
	2.88	43.9	2.88	40.1	42.0	3.7	43.9	40.1
	2.95	44.5	2.95	44.0	44.2	0.5	44.5	44.0

In a similar study in the State of New York in 2011 by the New York State Thruway Authority, skid data in terms of friction number FN40 was collected on right, center, and left lanes of a two-mile section on a state highway. The control data constitutes FN40 before application of RePlay and two sets were also collected after RePlay application: one on the same day of application after curing has completed, and the other set collected one week later. The maximum, minimum, average, and standard deviation of FN40 collected within the two-mile section are shown in Table 2.

Inspection of the data reveals that the RePlay application did not negatively affect skid data. Skid resistance has improved with time to levels nearly similar or exceeding the original levels one week after application.

Table 2. Effect of RePlay on skid resistance measured on a New York state highway (NY State Thruway Authority)

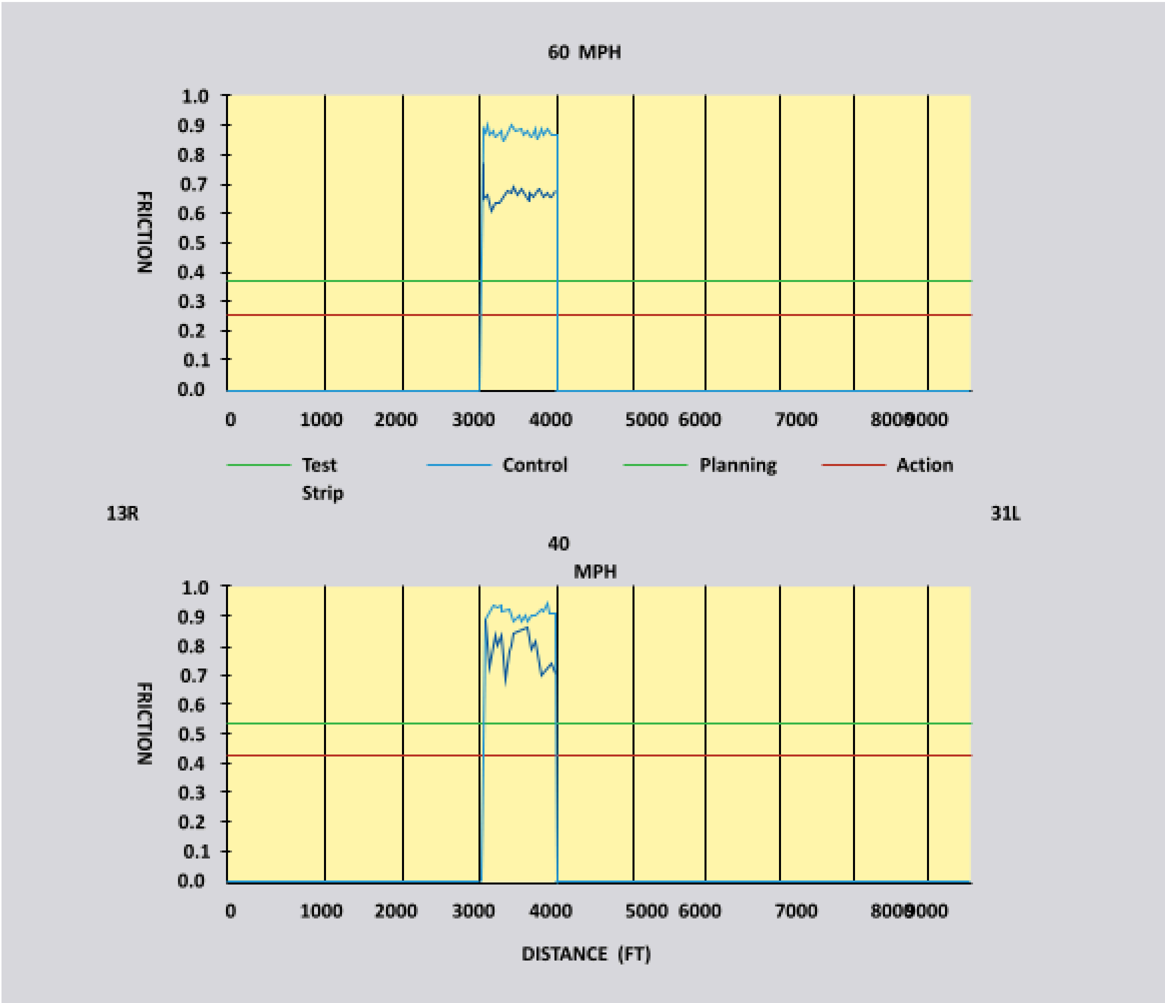
Lane	Statistic	Friction Number (FN40)		
		Before RePlay 10/18/2011	After RePlay 11/04/2011	After RePlay 11/10/2011
Right Lane	Max FN40	46.2	45.5	47.2
	Min. FN40	42.8	38.8	40.3
	Avg. FN40	44.8	40.5	42.2
	Std. Dev. FN40	0.8	1.5	1.6
Center Lane	Max FN40	47.7	41.0	45.8
	Min. FN40	40.3	36.0	37.9
	Avg. FN40	44.5	38.9	41.6
	Std. Dev. FN40	2.2	1.2	1.8
Left Lane	Max FN40	50.3	52.3	53.4
	Min. FN40	45.6	45.8	48.8
	Avg. FN40	48.0	50.5	51.6
	Std. Dev. FN40	1.2	1.5	1.1

The Tyndall Air Force Base in Florida also conducted testing of skid resistance on runway pavements treated with RePlay in comparison with skid of untreated sections[19]. The use of ecologically-friendly products such as RePlay is important because airports are extremely environmentally sensitive due to the huge amount of jet fuels, vehicle exhausts, and electrical power and heating and cooling required; all combined exerting tremendous stress on the environment.

Results of testing indicated that RePlay did not significantly affect skid as treated sections did not demonstrate friction properties above the minimum action value (red threshold line) or even above the planning value (green threshold line) as shown in Figure 3.

[19] BioSpan 2014

Figure 3. Friction tested on runways in Tyndall Air Force Base in Florida at 60mph and 40 mph speeds



Water Runoff

The City of Hutchinson conducted experiments on two asphalt paved surface to study the rate of water runoff[20]. This study was important because it is concerned with the safety of pedestrian's foot and bicycle traffic over wet surfaces following rain. One pavement test section was a 15-year old bicycle/pedestrian trail that has experienced raveling and cracking. The other section was a five-year-old paved driveway that did not show any major distresses on the surface except for some minor raveling.

The experiment involved a RePlay-treated section and a control (untreated) section in each pavement location. Water was poured onto all the pavement sections and the rate of runoff was visually observed. A significant difference was observed in the way water behaved on the trail and driveway pavement asphalt surfaces between the

[20] Olson 2011

treated and untreated sections. Wicking was most notable in the untreated sections; higher wicking was observed in the older raveled trail pavement than the newer driveway asphalt surface. On the contrary, water ran off the treated sections at a high speed without wicking into the surface.

Figure 4 shows photos of the experiment performed on the driveway pavement. Before treatment, water wicked into the surface as evidenced by the footprints and splash areas shown in Figure 4. Also, water ran off slowly toward the edges of the untreated pavement. The "after treatment" photos show that water ran off at a higher speed and the surface did not wick like it did prior to the RePlay application. Splash spots started to dry rather more quickly in the treated sections.

Visual inspection of the pavements prior and after RePlay application revealed RePlay has sealed the asphalt surface. The treated pavements retained dark wet-looking appearance for 2 weeks after application, after which the dark color started to fade slowly. After 6 weeks, it was not possible to visibly distinguish treated surface from untreated surfaces[21].

Figure 4. Runoff experiments on an asphalt driveway before and after treatment with RePlay.

This experiment concluded that the application of RePlay as a bio-based sealer is not only effective in sealing off the surface and removing water runoff quickly, but also safe to the environment. Unlike petroleum based sealers that are unsafe to the environment and both inconvenient and undesirable for areas with high pedestrian traffic, RePlay is agricultural based product that cures quickly, with traffic back on the pavement in less than 30 minutes, and can penetrate to replenish (rejuvenate) with essential Superpave polymers the top ¾" to 1 ¾" of the asphalt surface layer. The

[21] Olson 2011

odor produced by RePlay is similar to that of citrus degreaser, and not unpleasant making this product suitable for application in residential areas for sealing roads, driveways, parking areas, etc.

It has also been reported that water poured on a RePlay-treated asphalt surface will bead on the surface aiding the drainage and fast removal of water off the surface[22]. Figure 5 shows two photos obtained from a different project[23] depicting the fast runoff of water on an asphalt pavement treated with RePlay.

The use of RePlay also offers other advantages to the environment compared to petroleum-based seals. Since petroleum-based seals do not cure completely and do not penetrate deep enough into the asphalt matrix, run off can occur for several weeks after application. This increases the risk of groundwater contamination and can kill fish when runoffs enter water streams.

In comparison, RePlay is hydrophobic, and primarily agricultural-based product, thus it will not dissolve in water and is non-toxic. Therefore, unlike petroleum-based products, RePlay poses no risk to groundwater or aquatic life.

Figure 5. Fast removal of runoff water on asphalt pavement surface treated with RePlay (BPS 2014).

[22] Surface Green 2014
[23] BPS 2014

LABORATORY STUDIES

Pavement Texture

ASTM E965[24] "The Sand Patch" or Volumetric Patch Test is the most commonly used test method to measure pavement macro-texture or texture depth in pavement. The test consists of spreading out a known volume of standardized sand or small glass spheres over the pavement surface using a flat disk. The sand or glass spheres are distributed to form a circular patch. A small circle diameter indicates a high average texture depth; a larger circle diameter indicates a low average texture depth. The known volume of sand divided by the surface area covered by the sand (measured on site) yields the average texture depth. When comparing two samples (or locations) using this method, the results can effectively reveal if a product has reduced the number of voids in a surface.

In one study, the Sand Patch test was conducted on several samples extracted from two asphalt pavements from the City of Regina (Saskatchewan, Canada) before and after treatment with RePlay[25]. The sand patch test measures the macro texture of the asphalt and allows for determining the mean texture depth (MTD).

Results of testing indicated a reduction in MTD by 8% for one pavement surface and by 25% for the other. This indicates that the penetration of RePlay into the surface pores has closed the surface significantly; thus, providing for a barrier to air, water, chemical contaminants, and de-icing salt intrusion into the voids within the pavement. Figure 6 shows a picture of one of the pavement surfaces tested before and after treatment with RePlay.

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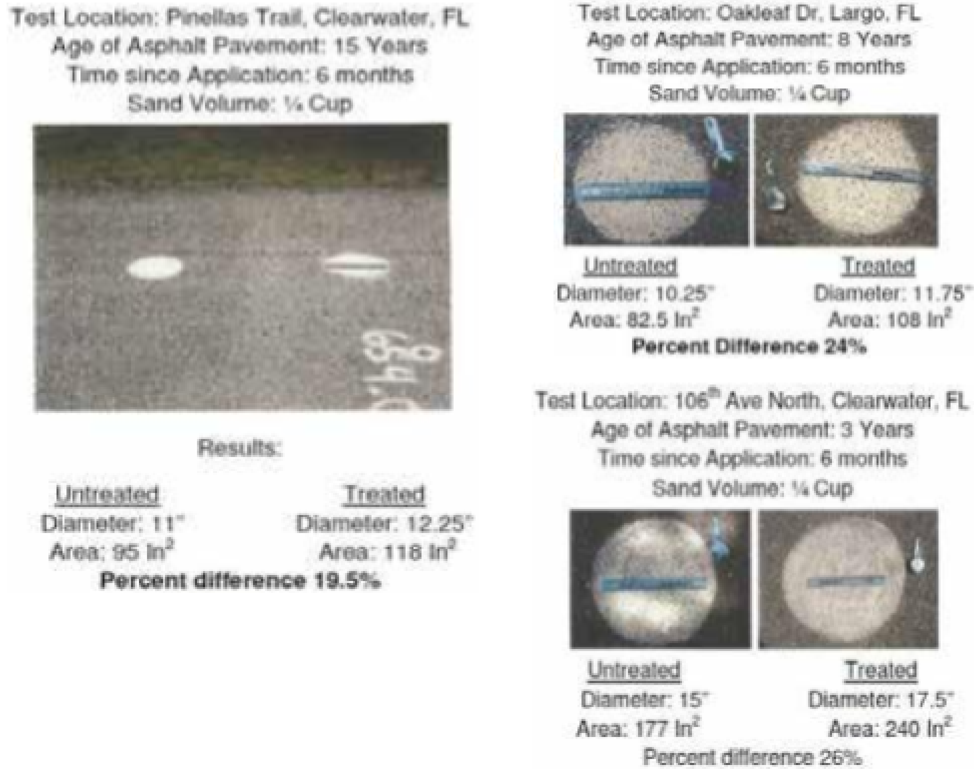
[24] ASTM E965 Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique
[25] Massier 2010

Figure 6. Surface texture of one of the asphalt pavements tested.

In another study[26], The Sand Patch test was tested. performed on three pavements in Largo and Clearwater, Florida varying in their age both before treatment and 6 months after treatment with RePlay. It was found that the MTD dropped by 19.5%, 24%, and 26%, respectively, for the 15-, 8-, and 3-year old pavements tested before and after the application of RePlay. Figure 7 shows test locations and calculations for the three locations. The test results indicated that RePlay helped fill voids in the tested asphalt pavements, in a range from 19.5% to 26%, thereby sealing out moisture and reintroducing new polymers into those voids to add strength and flexibility, while maintaining skid resistance.

[26] KMS 2006

Figure 7. Sand Patch test results for three city streets in Florida



Pavement Permeability

Besides conventional dense asphalt pavements, there are pervious asphalt pavements that are especially designed and constructed to drain quickly. Therefore, the use of bituminous seal coats on these pavements is not permitted which would otherwise force this type of pavement to lose its drainage capability. Unlike conventional sealers, RePlay has significantly lower viscosity than normal asphalt sealers; therefore, it is capable to penetrate deeper into the pervious pavement and rejuvenate and strengthen the binder with new polymers without clogging the internal porous structure of the pavement.

Additionally, RePlay is hydrophobic, so the internally RePlay-coated porous structure within the asphalt concrete tends to repel the water that passes through draining it at a higher speed. The water permeability increases by coating particles of the internal structure with RePlay due to the significantly reduced tendency of water to absorb into the stone-binder matrix and the repulsion forces mobilized in the matrix.

Conventional non-porous pavements were also tested before and after treatment with RePlay. RePlay tends to fill voids on the asphalt concrete surface as was also evidenced from sand patch tests conducted on asphalt concrete surfaces to measure effect on texture, as discussed previously. Results of permeability testing of a set of treated and untreated asphalt concrete samples are shown in Table 3. As can be seen, the permeability of treated asphalt concrete specimens has significantly dropped due to sealing the surface with RePlay compared to untreated specimens.

Table 3. Permeability testing of RePlay-treated and untreated conventional

		Untreated Samples			**Treated Samples**		
Specimen I.D.		1	2	3	4	5	6
Inside cross sectional of the buret, cm^2	a=	8.00	8.00	4.00	5.00	6.00	7.00
Average thickness of the test specimen, cm	L=	3.00	2.90	4.00	3.60	3.10	2.80
Average diameter of test specimen		15.20	15.20	15.20	15.20	15.20	15.20
Average cross-section area of test specimen, am^2	A=	725.83	725.83	725.83	725.83	725.83	725.83
Elapsed time between h_1 and h_2, s	t=	60.0	31.0	900.0	343.0	900.0	900.0
Initial buret reading, mm		631.0	631.0	631.0	631.0	631.0	631.0
Final buret reading, mm		0.00	0.00	41.00	0.00	5.00	8.00
Initial head across the test specimen, cm	h_1 =	86.58	86.48	86.88	87.18	86.68	86.38
Final head across the test specimen, cm	h_2 =	23.38	23.38	27.88	24.08	24.08	24.08
Temperature of water, OC		25.0	25.0	25.0	25.0	25.0	25.0
Temperature correction for viscosity of water	t_c =	0.89	0.89	0.89	0.89	0.89	0.89
$k=(aL/At)In(h_1/h_2)t_c$							
Coefficient of Permeability ($x10^6$ cm/s)**		64	120	2	8	3	3

To experimentally examine the efficacy of RePlay as a surface sealant for asphalt pavements, the City of Edmonton, Alberta, Canada conducted absorption testing in 2009 on a number of asphalt cores obtained from the City street's asphalt pavements[27]. The purpose of the experiment was exactly to determine how RePlay seals the asphalt concrete within the pore structures and along the micro-cracks. All cores were weighed, and their density and air voids content determined using ASTM D 2726[28] and ASTM D 3203[29] respectively.

All core samples were dried in a forced air oven at 40oC to a constant weight. Four core samples were then selected and surface-coated with RePlay at the manufacturer recommended application rate. Two more core samples were used as control without surface sealant applied. The treated core samples cured for 1 hour before they were transferred to the water bath at room temperature and kept submerged, as shown in Figure 8.

[27] Donovan 2013
[28] ASTM D2726: Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures
[29] ASTM D3202: Standard Test Method for Percent Air Voids in Compacted Asphalt Mixtures

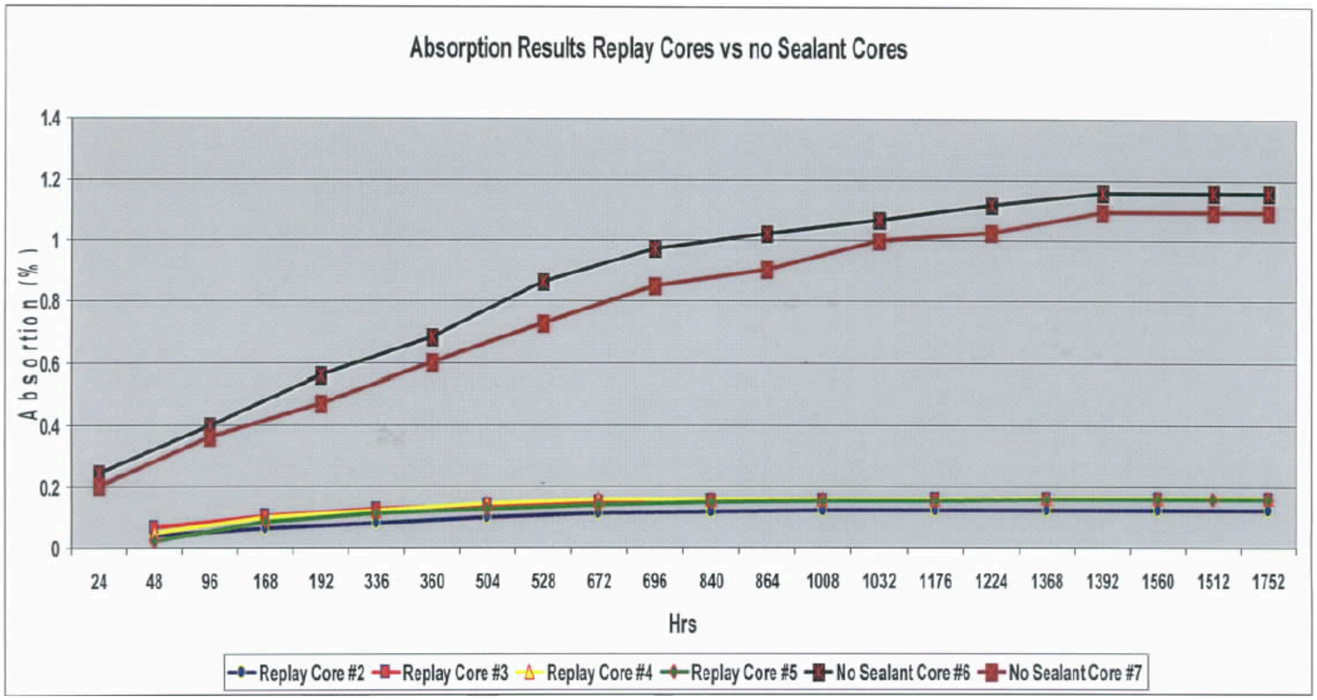
The control core samples were transferred into another water bath and kept submerged at room temperature. All core samples (treated and control) were weighed weekly (after gently drying their surfaces with an absorptive towel), immediately returned to the water bath, and then the amount and percentage of absorbed water were determined for each core sample. This process was continued until the core's weight remained constant indicating that the sample cores were fully saturated.

Figure 9 shows the water absorption percentage for all the core samples for a total submersion period of 1752 hours (73 days). As seen in Figure 9, there is a definite reduction in the amount of water absorbed into the sealed samples (lower curves) compared with the control samples (upper curves).

The untreated samples absorbed as much as 10 times the amount of water absorbed by the samples treated with RePlay. The reduction of water movement in the treated samples is desirable because it will reduce the damaging effect of water on the asphalt mix (a distress called asphalt stripping); thus, extending the serviceability of the asphalt pavement.

Figure 8 Water Bath for Asphalt Test Pucks

Figure 9. Water absorption into RePlay-treated and untreated core samples



Polymers Penetration

FT-IR (Fourier Transform-Infrared) spectroscopy is a widely-used technique for identifying chemical composition of a product. To investigate the polymer permeation of the asphalt mixture when sealed with RePlay, samples were obtained from the surface course of a PG 84-22 asphalt pavement from the state of New York and tested using FT-IR spectrometer.

Untreated samples were also tested with the FT-IR spectrometer to examine the available air voids and to serve as Control. Figure 10 shows images of both the control and RePlay-penetrated samples along with their corresponding FT-IR scans. As can be seen in Figure 10a and Figure 10b, there is a noticeable difference in the FT-IR scans between the Control and treated samples at ½" depth.

The FT-IR scan of the treated sample demonstrates the penetration of polymers (both SBS and SBBS) from RePlay at ½" depth as compared to the Control scan. Quantitatively, RePlay adds over 15% of new SBS and SBBS polymers to the asphalt binder in the mix. Successive FT-IR scans revealed polymers penetration to a depth from 0.75" to 1.25" into the mixture from the surface.

A description of the polymer permeation process of a PG 84-22 asphalt concrete samples at 1.25" depth along with 40x magnified images of the internal pore structure are shown in Figure 11 in comparison with a control sample.

Figure 10a. Images at 40x magnification of the voids and FT-IR scan of control asphalt concrete samples at ½" depth (Cochran Engineering, Inc., Union, MO).

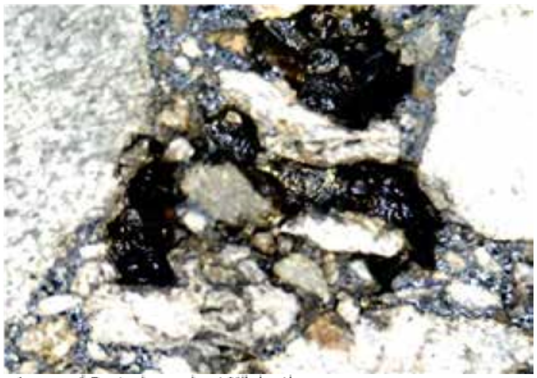


Image of Control sample at ½" depth

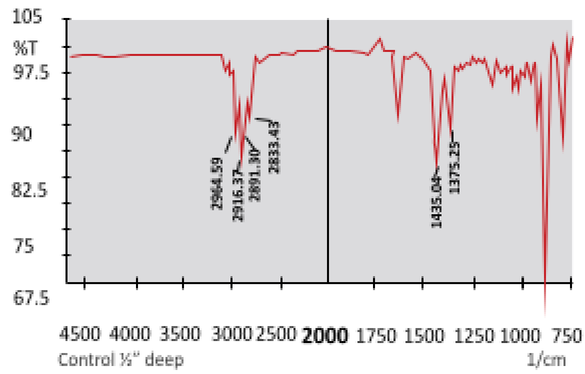


Figure 10b. Images at 40x magnification of the voids and FT-IR scan of treated asphalt concrete samples at ½" depth (Cochran Engineering, Inc., Union, MO).

Image of Treated sample at ½" depth

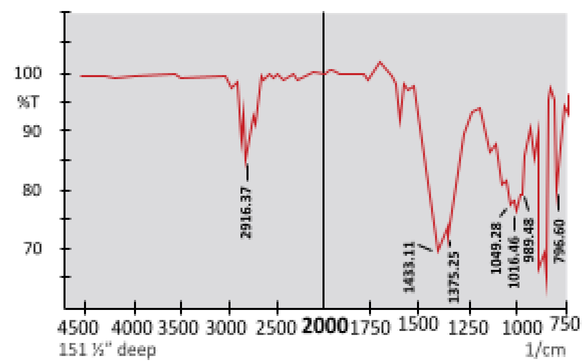
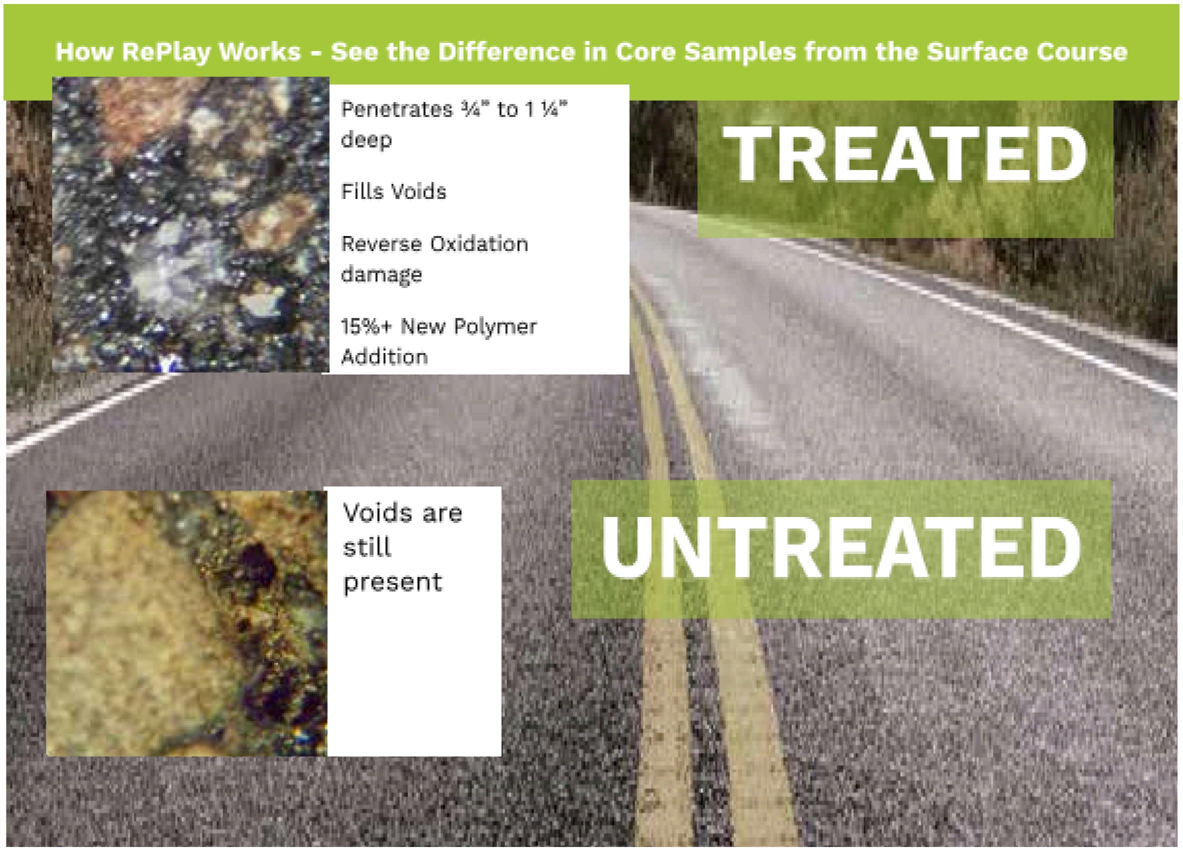


Figure 11. Polymer penetration with RePlay of a PG 84-22 asphalt concrete sample at 1.25" depth compared to untreated sample.

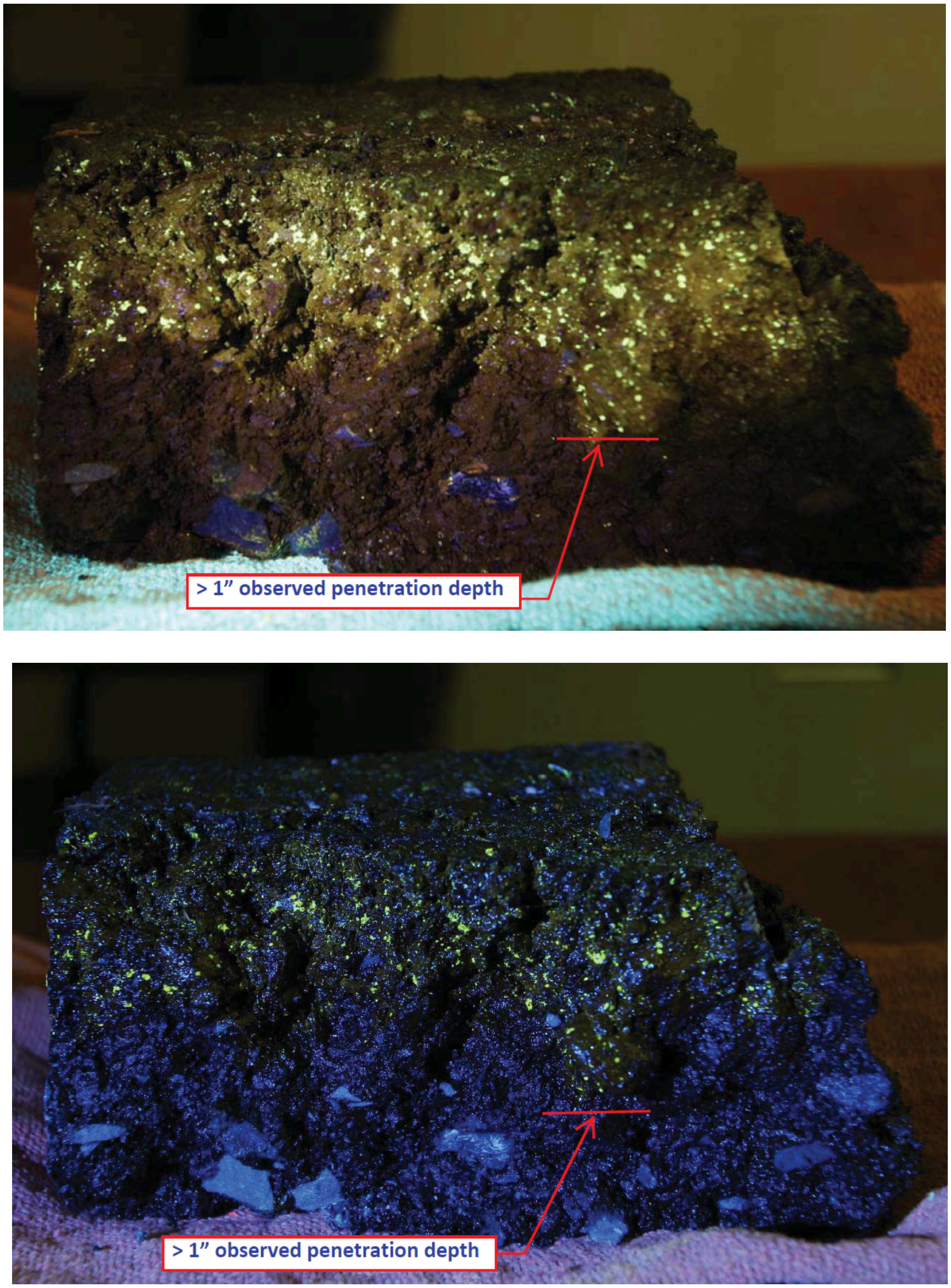


Visual Testing of Penetration

In a different study[30], the penetration depth of RePlay into a number of asphalt concrete specimens treated with RePlay at various application rates was visually inspected in a darkened room with the aid of blue light and black light flashlights. Inspection of treated specimens revealed that the penetration of RePlay into the asphalt samples was visually observed at least one inch below the surface, as can be noticed in one of the samples shown in Figure 12. Additionally, it was also concluded that penetration was deeper than what was visually observed as evidenced with the temporary softening of the asphalt mixture, smelling the citrus fragrance, and the presence of oil residue picked up on the fingers when the asphalt matrix was wiped below the visually observed penetration depth of one inch[31].

[30] Bio-Pave Products 2014
[31] Bio-Pave Products 2014

Figure 12. RePlay penetration in one of the asphalt concrete samples as observed with the aid of: (a) black light and (b) blue light flashlight.



Mechanical Properties

The effect of the soybean oil-based sealer and rejuvenator RePlay treatment on the mechanical properties of asphalt concrete was investigated in a series of laboratory experiments on both treated and untreated (control) specimens cut out from cores obtained from actual in-service roadway asphalt pavements[32]. The tests that were performed on the specimens included:

Marshal stability test (ASTM D 1559[33]): Stability and flow of core samples were measured at 60oC.

Retained stability test (ASTM D1075[34]): This test measured stripping resistance of asphalt concrete mixtures. Specimens were kept in a water bath at 60oC for 24 hours and then tested for stability using the Marshal apparatus. Retained stability is the percentage of Marshal stability of saturated samples compared to stability determined in normal conditions.

Moisture susceptibility (AASHTO T 283[35] and ASTM D4867[36]): These tests measure resistance of mixtures to moisture susceptibility. In order to examine the effect of RePlay treatment on the asphalt mixture's resistance to moisture damage, the loss of adhesion of the bitumen with the aggregate is characterized by determining the tensile strength ratio (TSR) the ratio of indirect tensile strength (ITS) of wet specimen to the indirect tensile strength of dry specimen.

Dynamic creep test: This test was conducted by subjecting the samples to repeated axial loading consisting of a haversine wave with 100 kPa peak stress and 1 Hz frequency. The load was applied for 0.1 sec followed by 0.9 sec rest period. The accumulated strain and creep modulus were determined after applying a maximum of 3600 loading cycles.

Binder recovery test (ASTM D2172[37] and ASTM D1856[38]).

Table 4 summarizes the results of the various laboratory tests conducted on both the control and treated specimens. As Table 4 shows, the results of testing of both the core samples and recovered bitumen of untreated (control) and RePlay-treated specimens indicate that the application of RePlay improves the mechanical properties of the binder in the wearing surface of the roads.

[32] CRRI 2010
[33] ASTM D1559: Test Method for Resistance of Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
[34] ASTM D1075: Standard Test Method for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures
[35] AASHTO 283: Standard Test Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage
[36] ASTM D4867: Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures
[37] ASTM D2172: Standard Test Method for Quantitative Extraction of Asphalt Binder from Asphalt Mixtures
[38] ASTM D1856: Standard Test Method for Recovery of Asphalt from Solution by Abson Method

Table 4. Mechanical properties of untreated and RePlay-treated asphalt concrete specimens.

Test	**Untreated (control)**	**RePlay -Treated**	**Change**	**Notes**
Stability (kg)	924	1013	+9.6%	Improved strength due to treatment
Flow (mm)	2.9	3.1	+6.9%	Flow of modified samples is within acceptable range of 2-4 mm per the Asphalt Institute recommendations (Asphalt Institute 1979).
Dry ITS (kg/cm2)	16.1 6	15.64	-3.2%	Slight decrease but not detrimental.
TSR (%)	64.2 4	81.65	+27.1%	Improved moisture susceptibility of modified samples.
Retained stability (%)	73.2 3	83.42	+13.9%	Improved retained stability due to treatment.
Accumulated strain at end of 3600 cycles (%)	0.71	0.60	-15.5%	Lower values of modified specimens indicate high resistance to permanent deformation.
Penetration of recovered bitumen (0.1 mm, 25oC)	24	37		Result indicates improved performance of modified bitumen.
Softening point of recovered bitumen (oC)	58	52		Result indicates improved performance of modified bitumen.
Ductility of recovered bitumen at 27oC (cm)	33	47		Result indicates improved performance of modified bitumen.

REPLAY EFFECT ON RHEOLOGICAL PROPERTIES OF IN-SERVICE ASPHALT

The most recent verification study on the effectiveness of RePlay on in-service asphalt concrete pavements included examining its effect on the rheological properties of the asphalt binder used in construction of a 2-inch asphalt concrete overlay of a section of 168th Street in Douglas County, Nebraska[39], followed with the application of the RePlay bio-sealant. Another segment of the newly constructed overlay did not receive any RePlay application and was used as the control (untreated) section against which the RePlay-treated section would be compared.

The two-inch asphalt concrete overlay was placed over an existing flexible pavement between June 9 and June 24, 2016. The asphalt concrete mix used in paving consisted of the Nebraska Department of Transportation (NDOT) SPR Coarse Mix containing 75% virgin aggregate and 25% reclaimed asphalt pavement (RAP). A PG 64-34 asphalt binder was used in the mix. Approximately three months following overlay placement, RePlay was applied on the section of the road designated to be the RePlay-treated section. Another section was not treated and was designated as the Control section. In June 2017 and after allowing the overlay sections (both RePlay- treated and untreated) undergo some aging under direct sunlight (UV effect) and one winter season (water effect), cores from the overlay (6 from the treated section and 6 from the untreated section) were extracted for laboratory testing and evaluation.

The cores were trimmed to remove all the old asphalt concrete leaving only the top new asphalt concrete. Each core was then sliced into three thin discs each 3/8-inch thick. Table 5 provides a schematic of the initial core and the thin discs. Slicing the cores throughout the depth of the overlay was performed to assist in examining the penetration depth (influence zone) of RePlay through evaluating a set of rheological and chemical performance indicators measured for each individual disc (i.e., at various depths). For each core, the discs were designated as follows (see Table 5):

Top 3/8 inch representing the asphalt concrete from the surface down to 3/8 inch depth, Middle 3/8” representing the asphalt concrete between ½-inch and 7/8-inch

[39] Additional testing on binders recovered/extracted from cores obtained from an asphalt pavement placed in a cold region in California has also been performed and related to low temperature cracking resistance evaluation using the bending beam rheometer test is discussed at the end of this section

depths (allowing for 1/8 inch saw kerf between discs), and Bottom 3/8" representing the asphalt concrete between 7/8 inch and 1 ¼-inch depths.

Mechanical Properties

A series of tests were conducted on the fabricated core discs shown in Table 4 to assess the performance benefits of RePlay-treated asphalt concrete samples compared to the untreated samples. The tests are briefly discussed below:

1 Texas Overlay Test[40]: This test was developed by the Texas Department of Transportation (TxDOT) to determine the susceptibility of bituminous mixtures to fatigue and reflective cracking. The test determines both the critical fracture energy (Gf) and crack resistance index (CRI) as performance indices that characterize the bituminous mixtures resistance to cracking. In this test, the electro-hydraulic system of the overlay tester (OT) device applies repeated direct tension loads to an asphalt concrete specimen mounted to two blocks: one is fixed and the other slides horizontally. The device automatically measures and records load, displacement, and temperature every 0.1 sec.

2 Dynamic Shear Rheometer (DSR)[41]: This test is used to characterize the linear viscoelastic (i.e., both viscous and elastic) properties of asphalt binders at medium to high temperatures. This characterization is used in the Superpave PG asphalt binder specification. In the basic DSR test, a thin asphalt binder sample is placed between two circular plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample at 10 rad/sec to create a shearing action. Generally, the DSR test is applicable to asphalt binders having dynamic shear modulus values in the range from 100 Pa to 10 MPa which is typical for binders at temperature between 6 and 88°C. This test determines the dynamic shear modulus (G*) and phase angle (δ) of the tested asphalt binder. The tests can be conducted on unaged, RTFO-aged (representing short-term aged) and PAV-aged (representing long-term aged) asphalt binder specimens.

3 SARA Components[42]: This test method covers the separation of four defined fractions from petroleum asphalts. The four fractions are defined as saturates, naphthene aromatics, polar aromatics, and iso-octane insoluble asphaltenes. Analytical testing of these fractions can be used to evaluate asphalt composition. The results of this test may be used to compare the ratios of the fractions from one asphalt binder to another binder; for example, for the evaluation of aging that affects these fractions in relation to performance properties of the asphalt binder and asphalt concrete mixture.

[40] TEX-248-F: Test Procedure for Overlay Test

[41] AASHTO T315-12: Standard Test Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer

[42] ASTM D4124-09: Standard Test Methods for Separation of Asphalt into Four Fractions

4 Carbonyl Index[43]: This test procedure describes techniques for qualitative analysis of liquid, solid-, and vapor-phase samples by infrared spectrometric techniques. Among these techniques is the Fourier Transform Infrared Spectroscopy

(FTIR) which is widely used for identifying organic and inorganic materials. This chemical oxidation of asphalt binders, which is an indicator of aging associated with exposure to sunlight.

Table 5. The location of the three discs trimmed from the extracted cores along with description of the various tests performed on the RePlay-treated and untreated specimens.

Core (6 Treated + 6 Untreated)	Disc Slices from Core	Description of Test Specimen	Test Performed and Properties Determined
		Top 3/8” disc (treated or untreated), six replicates each from one of 6 cores retrieved	DSR (1), SARA components (2), Carbonyl Index (3)
		Middle 3/8” disc (treated or untreated), six replicates each from one of 6 cores retrieved	DSR (1), SARA components (2), Carbonyl Index (3)
		Bottom 3/8” disc (treated or untreated), six replicates each from one of 6 cores retrieved	DSR (1), SARA components (2), Carbonyl Index (3)
		Entire core with the new asphalt overlay used to prepare Overlay Tester specimen	Texas Overlay Tester (4)
(1) Determine the asphalt binder’s dynamic shear modulus (G*) and phase angle (δ) using AASHTO T 315. (2) Determine concentration of saturates, naphthene aromatics, polar aromatics, and asphaltenes in asphalt binder using ASTM D 4124. (3) Determine Carbonyl Index of the asphalt binder using ASTM E1252. (4) Determine cycles to failure (Nf), critical fracture energy, and Crack Resistance Index (CRI) of the asphalt concrete mix using TEX 248-F.			

[43] ASTM E1252: Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis

Cracking Resistance

Replicate specimens for the overlay tester were prepared following test method TEX-248-F from cores (both treated and untreated) taken from the pavement. The overlay tester method is routinely used at TxDOT for the laboratory characterization of the susceptibility of bituminous mixtures to fatigue or reflective cracking. Three parameters (properties) were determined from the test results:

1. The number of cycles to failure (Nf). It has been determined in other studies that this parameter was not the best measure of performance of the mixture in the Texas overlay Tester (Garcia et al. 2017).

2. The critical fracture energy (Gf) represents the energy required to initiate a crack on the bottom of the specimen at the first loading cycle of the overlay test. It is determined from a plot between peak load and displacement and represents the area under the load-displacement curve up to the maximum load. This parameter characterizes the fracture properties of the specimen during the crack initiation phase.

3. The crack propagation rate represents the flexibility of the mix to attenuate the propagation of the crack. The crack propagation rate is determined from a plot of the peak load versus number of cycles. For a better interpretation of the crack progression, the crack propagation data is used to determine the Crack Resistance Index (CRI) of the mix by fitting the data to a simple power function[44] in which the function exponent is the CRI. The index characterizes the flexibility and fatigue properties of specimens during the crack propagation phase. The CRI is measured on a scale from 0 to 100 (i.e., from less flexible to more flexible), and the higher the CRI the better the mix.

   Unlike the number of cycles to failure, the Gf and CRI were found to be more repeatable and reliable than the Nf (Garcia et al. 2017). Ideally, a crack-resistant mix must possess the following two characteristics (Miramontes 2017: (1) the mix must be tough enough to not allow a crack initiation, and (2) the mix should be flexible enough so that it will attenuate the rate of propagation of the crack after it has started. In other words, from the second cycle on, the rate of crack propagation must be gradual. Analyzing acceptable versus unacceptable Texas asphalt concrete mixes on an interaction plot (a plot of CRI vs. Gf) indicated that the Gf must be a minimum of 1.0 lb-in/in2 and the CRI a minimum of 70 for a good mix in terms of crack resistance. Therefore, the higher the CRI and the higher the Gf the better is the performance of the mix in terms of cracking resistance and cracking progression.

[44] P=N0.0075o-1.0, where P is the peak load, N is the cycle number, and o is the CRI determined by numerical fitting of the (P,N) load-displacement data

Results on RePlay-treated and untreated mixes are shown in Table 6. It is evident from Table 6 that both the treated and untreated mixes exhibited similar performance in terms of cycles to failure; a parameter that was found to be inadequate to characterize cracking susceptibility of asphalt concrete mixes. Based on CRI-Gf interaction plot (CRI>70, Gf>1.0 lb-in/in2) both mixes are "good" in terms of cracking performance; however, the RePlay-treated mixes have slightly better cracking performance than the untreated mixes (based on crack initiation characterized by CRI and crack progression characterized by Gf).

Table 6. Results of the Texas Overlay Tester on RePlay-treated and untreated specimens.

Test Method No. and Name	Property Directly Measured from the Test or Calculated	Results [1]		Percent % Improvement in Property
		Untreated [2]	Treated [2]	
TEX 248F Texas Overlay Tester	Cycles to Failure, Nf	>1000	>1000	-----
	Critical Fracture Energy, Gf ($lb\text{-}in^2$)	1.68	2.04	21%
	Crack Resistance Index (CRI)	96.67	103.47	7%
[1] Test run at 25°C [2] Average of 6 Specimens				

Recovered Binder Rheology

For testing the binder rheology, each set of cores were cut in 3/8" discs and grouped together as top, middle and bottom layers for untreated and treated specimens. The binder was then centrifuge-extracted per ASTM D 2172[45] (Method A) using toluene. Rotovap recovery (ASTM D 5404[46]) was then performed to separate the binder for testing in the Dynamic Shear Rheometer (DSR). In these tests, no laboratory aging of the binder was performed. However, the new overlay was subject to weather aging for at least one year before sampling. This is assumed to be equivalent to laboratory short term aging resembling the rolling thin film oven (RTFO) aging. Superpave addresses rutting of unaged and RTFO-aged binders using the rutting factor (G*/sin δ) where G* is the dynamic shear modulus and δ is the phase angle. For unaged binder, Superpave requires that (G*/sin δ)≥1.00 kPa and ≥2.2 kPa for RTFO-aged binder. Binders with values below these may be too soft to resist permanent deformation. From the standpoint of rutting resistance, higher values of G* (stiffer) and lower values of δ (more elastic) are considered desirable attributes.

Table 7 summarizes results of the rheological properties testing of the extracted treated and untreated asphalt binders. Comparison of the untreated versus RePlay-treated (G*/sin δ) indicates that the untreated binders extracted from the untreated

[45] ASTM D2172: Standard Test Method for Quantitative Extraction of Asphalt Binder from Asphalt Mixtures

[46] ASTM D5404: Standard Practice for Recovery of Asphalt from Solution Using Rotary Evaporator

specimens underwent some aging (as expected) due to one year exposure to weather action prior to sampling compared with the treated binders. This is reflected in the higher (G*/sin δ) values measured with the DSR for the untreated specimens at the three test temperatures. The RePlay-treated binders extracted from specimens retrieved one year after construction resembled unaged binders in their (G*/sin δ) values which were close to the Superpave minimum of 1.0 kPa. The higher (G*/sin δ) values of the untreated specimens indicate oxidative aging which did not affect the specimens that were treated with the bio-sealant RePlay. It is also obvious from Table 7 that the higher (G*/sin δ) values were found in the top 3/8" specimens due to exposure of the top layer to direct sunlight. This seems to have affected all specimens; however, the RePlay-treated specimens evidently were more aging-resistant than the untreated specimens based on the measured (G*/sin δ) values.

Considering the 2.2 kPa (G*/sin δ) RTFO-aged criterion, the Performance Grade (PG) high temperature was determined by interpolation for the binder in the top, middle, and bottom specimens, and is summarized in Table 7 (labeled as Pass/Fail high temperature). It is evident from Table 7 that the interpolated PG high temperature was greater for the untreated specimens than for the RePlay-treated specimens. This exhibits an increased aging of the untreated binders compared to their treated counterparts. The interpolated PG high temperature after one year of aging as shown in Table 7 are to be compared with that of the unaged virgin binder used on the project (i.e., PG 64-34). The percentage increase in the PG high temperatures (virgin interpolated versus unaged equals to 64oC) was calculated as an indicator of the aging effect on both the RePlay-treated and untreated specimens. As shown in Table 7, the percentage increase in the PG high temperature was greater for the untreated specimens indicating a greater level of oxidative aging. Finally, based on (G*/sin δ) values reported in Table 7, the penetration depth of the RePlay rejuvenator was effective down to ~1.0 inch.

Table 7. Results of the rheological property (G*/sin δ) of the treated and untreated recovered asphalt binders determined with the dynamic shear rheometer.

Property	Test Temp	Top 3/8" discs		Middle 3/8" discs		Bottom 3/8" discs	
		Untreated	Treated	Untreated	Treated	Untreated	Treated
(G*/sin δ), kPa [1] AASHTO T 315	64oC	8.72	4.52	6.74	2.75	3.83	3.00
	70oC	4.79	2.34	3.86	1.49	2.13	1.60
	76oC	2.71	1.23	2.27	-	-	-
Pass/Fail high temp. (oC) [2]		78.3	70.6	76.4	66.2	69.7	67.3
Unaged binder high temp. (oC) [3]		64.0	64.0	64.0	64.0	64.0	64.0
Increase in PG high temp.		22.3%	10.3%	19.3%	3.4%	8.9%	5.2%

1 δ=10 rad/sec.

2 Interpolated PG high temperature corresponding to (G*/sin δ) of 2.2 kPa.

3 The asphalt binder used in overlay construction was PG 64-34.

Chemical Analysis

Both the asphaltene fraction and the Carbonyl Index (CI) are sometimes used as indicators of asphalt oxidation (aging). Both the asphaltene fraction and the CI tend to increase as the asphalt binder gets oxidized through the aging process. Oxidation creates carbonyl (C=O) groups (determined with FTIR spectroscopy) that tend to harden the asphalt binder (thus becoming more brittle). Results of the chemical analysis and FTIR spectroscopy performed on the binders recovered from the RePlay-treated and untreated specimens at the three depths within the overlay are summarized in Tables 8.

The asphaltene fraction was found to be lower in the recovered binder of the RePlay-treated specimens for the three depth ranges sampled than the recovered untreated binder. This indicates that the RePlay rejuvenator is effective throughout the entire thickness of the overlay (i.e., 2.0”) as an aging retardation compound. Similarly, Table 8 shows that the carbonyl index (CI) showed effectiveness in the top 3/8” of the overlay, but results were inconclusive in the middle and bottom 3/8” portions of the overlay.

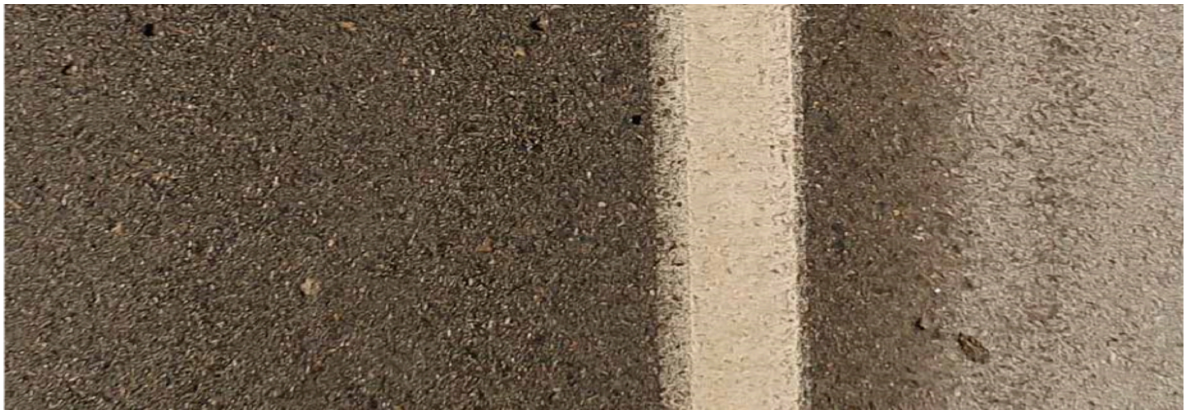
The discrepancy in using the CI as a marker for asphalt aging has been reported in several other studies[47], and was to be inconclusive in terms of pavement performance. Other researchers[48] have also found (through round-robin testing of aged binders) that the greatest discrepancies in the index values are primarily due to the index calculation methods.

Table 8. Fractions (percentages) of the four SARA components and the Carbonyl Index of the recovered binders at three depths within the asphalt overlay.

Test	Property	Top 3/8”		Middle 3/8”		Bottom 3/8”	
		Untreated	Treated	Untreated	Treated	Untreated	Treated
SARA Component s (ASTM D4124) by Iatroscan	Saturates	9.9%	8.2%	9.1%	8.4%	8.7%	9.1%
	Naphthene aromatics	32.7%	21.6%	28.1%	30.6%	28.5%	27.5%
	Polar aromatics	36.0%	50.4%	41.1%	40.7%	37.0%	39.7%
	Asphaltenes	21.4%	19.8%	21.7%	20.3%	25.7%	23.7%
Carbonyl Index (ASTM E1252)	Carbonyl Index	x 160	150	100	150	50	80

47 Kanbar 2010

48 Dony et al. 2016



A key benefit with RePlay applications, there is no need to restripe after treating the asphalt

Low Temperature Cracking

When the pavement temperature decreases, the asphalt concrete shrinks. Because friction resists movement of the asphalt concrete against the layer beneath it, tensile thermal stresses build up in the asphalt concrete. Low temperature cracks occur when the magnitude of the developed tensile stresses exceed the asphalt concrete tensile strength. The bending beam rheometer is used to characterize the low temperature cracking of the asphalt binder. A small creep load to a binder beam specimen is applied and the creep stiffness (the binder's resistance to load) of the specimen is determined. A very high creep stiffness is not desired since it indicates a brittle behavior of the asphalt at low temperature; thus, increased potential for thermal cracking.

Superpave requires that the creep stiffness has a maximum limit of 300 MPa. In addition to stiffness, the rate at which the binder stiffness changes with time at low temperatures is characterized using the m-value. A high m-value is desirable for a given binder. This is because as the temperature decreases and thermal stresses build up, the stiffness will change relatively fast. This means that the binder will tend to quickly release built up stresses thus preventing low temperature cracking from occurring. The Superpave binder specification sets a minimum m-value of 0.300.

The bending beam rheometer (BBR) test was conducted on samples of an in-service pavement at the Clear Lake Riviera Community, Lake County, CA. The pavement was installed in September 2013, and the RePlay rejuvenator was applied (at 0.015 gal/yd2) in December 2013. An untreated area of the pavement that was not treated was also sampled to serve as Control. The two core samples (one treated and one untreated) were taken on June 20, 2017.

The top one inch of each core was removed for testing. The asphalt was extracted and recovered as prescribed in California Test Method 365. The bending beam rheometer testing was performed on the recovered binders in accordance with AASHTO T 313. Table 9 summarizes the results of BBR testing conducted at -12 C.

As can be seen in Table 9, the creep stiffness of the RePlay-treated binders is lower than that of the untreated binder (by ~26%) indicating a less brittle binder with a lower propensity for thermal cracking at low temperature (although both binders meet the Superpave requirement). Additionally, the m-value for the RePlay-treated binder is slightly higher but, unlike the untreated binder, meets the Superpave requirements. This indicates a greater tendency of the treated binder to release accumulated tensile stresses under low temperature conditions than the untreated binder.

Table 9. Bending Beam Rheometer (BBR) test results on RePlay-treated and untreated recovered binders.

Property	Untreated	RePlay-Treated
BBR Test Temperature (°C) AASHTO T 313	-12	-12
Creep stiffness (MPa)	282	223
m-value	0.294	0.305

CONSTRUCTION WITH REPLAY

General

RePlay can be applied on any paved asphalt surface including asphalt parking lots, streets, highways, highway rumble strips, airport runways and taxiways, trails, sidewalks, and even tennis courts. RePlay's application is quite straightforward; but the following must be taken into consideration:

1 Pavement surfaces must be swept and cleaned prior to treatment to remove any standing water, dirt, leaves, foreign materials, etc. This work must be performed using hand-brooming, power-blowing, or other approved methods.

2 The surface texture of the pavement must be checked prior to application of rejuvenator to verify a good skid value. It is not advised to apply any type of rejuvenator for pavements with low skid resistance. If required, skid resistance testing must be performed prior to application of sealant.

3 The material must not be applied to wet or damp pavement surfaces. Do not apply during rainy or damp weather, or when rain is anticipated within 1-2 hours after application. Pavement surface temperatures must be greater than 32oF, and outside air temperatures must be 40oF and rising.

4 It is best to apply RePlay using special agricultural spray equipment suited for the application of sealant and rejuvenation agents. A bituminous distributor can be modified to apply the agricultural bio-based oil sealant. A sprayer containing the product loaded into the back of a pickup or flatbed truck can also be used, as shown in Figure 13. A GPS system is sometimes used to ensure that the product is being applied precisely and uniformly over the surface. In almost all projects, only two workers will be required: one driver and another situated on the back of the truck to monitor the spraying equipment. Normally, one lane-mile of pavement requires ~2 hours to apply, and the pavement will be opened to traffic within 15-30 minutes after application. For smaller areas such as sidewalks, driveways, trail paths, etc. RePlay can be applied with a hand-held sprayer as shown in Figure 13.

5 The rate of application of the RePlay sealer depends on texture, porosity, and age of the asphalt pavement to be sealed. Application rate varies from 0.010 to 0.020 gallons per square yard (Surface Green 2014); and the average rate is 0.015 gallons per square yard.

6 Traffic must not be allowed on the roadway surface until RePlay has penetrated the pavement surface and fully cured. Generally, this takes between 20 and 30 minutes with 50 to 80oF; but cooler temperatures will cause the cure time to increase.

Figure 13. Application of RePlay (a) with a sprayer with a tank of RePlay loaded on the back of a pickup truck (BPS 2014) and (b) with a hand-held sprayer connected to a RePlay tank source.

Additional guidance regarding the proper application of RePlay to pavements can be found elsewhere.

Generic Specification

The following is a specification that can be used with projects involving the use of RePlay:

General:

The Work in this section consists of furnishing materials and equipment necessary to perform all operations for the application of an asphalt rejuvenating agent to approximately __ miles of asphalt concrete surface courses. The rejuvenation of surface courses shall be by spray application of an agriculture-based rejuvenating agent composed of soy oil derivatives and polymers. It shall be a Bio-based material with a minimum of 75% content.

Traffic:

Control of traffic in work zones shall be performed in conformity with this specification and regional DOT specifications. Disruption to traffic flow must be held to a minimum amount of time. Traffic safety is the most important concern. Traffic must not be allowed onto the roadway until materials have cured and skid numbers are back to acceptable standards. Sand cover will not be permitted. The rejuvenating material shall not obscure or obstruct any traffic stripping or raised reflective pavement markings from functioning correctly.

Performance:

A rejuvenation product must have a proven life cycle extension of 3 to 5 years depending on traffic volumes and environmental conditions.

Product description:

Sealant and preservation agent is a chemically engineered asphalt pavement sealer comprised of agricultural oils with polymers. It is designed to reverse the oxidation process and create a water impermeable layer to prevent further oxidation and potholing. The sealant and preservation agent's unique chemistry penetrates the asphalt matrix reducing moisture penetration and oxidation further down. The sealant and preservation agent may be used on all asphalt mixes for parking lots, city streets, county roads, airport runways, airport taxiways, and airport parking aprons. Due to the sealant and preservation agent's concentrated form, it is applied in very light application rates with computerized spray equipment.

The sealant and preservation agent provides a seal without harming pavement striping, so restriping is not required. The sealant dries at the surface to allow traffic back on the pavement after 30 minutes but continues to work within the asphalt for several weeks until the entire restorative process is complete. The sealant and preservation agent also places polymers into the asphalt binder, which will improve resistance to rutting, raveling, oxidation, temperature changes, and moisture penetration.

Specifications for Sealer and Polymer Binder	
Property	Requirement
Saybolt Viscosity at 77 F (25 C) ASTM D-244 *D7496	5-20 Sec
Residue by distillation, or evaporation (3)	12% min and 18% max
Percent Volatile	N/A
pH	3.0-5.0
Solubility In Water	Immiscible
Specific Gravity	0.8820-0.8860 ($H2O$=1.0)
Boiling Point	310-330 Degrees F
Flash Point, Tag Closed Cup (ASTM 56)	211 Degrees F
Density at 20 Degrees C	7.4 pounds per gallon
Dynamic Creep Accumulated Strain 3600 cycles	< 65%

Specifications for Treated Pavement	
Property	Requirement
Kinematic Viscosity ASTM D2170	20% INCREASE min
Residual Polymer Test at 1" TX533C	4% INCREASE min
Asphalt Ignition Oven Report AASHTO T308 05	1- 2% INCREASE
Penetration Treated vs Untreated Cores, 25 C	> 25% INCREASE
Softening Point Treated vs Untreated cores	10% reduction min
Ductility Treated vs Untreated Cores, 27C	> 30% INCREASE
Asphalt Ignition Oven AASHTO T308	1-2% INCREASE

Global Warming REDUCTION (LCA BEE's)	-400Kg CO2 eq.

Application experience:

The asphalt sealant and rejuvenating agent shall be applied by an experienced applicator of such materials. The applicator shall have a minimum of 5 years of experience in applying asphalt rejuvenators.

A project superintendent knowledgeable and experienced in application of the sealant and preservation agent must be in control of each day's work. The bidder shall submit a written experience outline of the project superintendent.

Application temperature/weather limitations:

The temperature of the sealant and preservation agent at the time of application shall be as recommended by the manufacturer. The sealant and preservation agent shall be applied only when the existing surface to be treated is thoroughly dry.

Handling of sealant and preservation agent:

Contents in totes shall be agitated before withdrawing any material for application. The cleanliness of the spreading equipment shall be subject to the approval and satisfaction of the Engineer. Each tote shall be accompanied by an FDA type certificate of analysis.

Application equipment:

Special pressurized agricultural spray equipment is probably best suited for the application of the sealant and preservation agent. The sealant can be applied using a specially adapted bituminous distributor that is properly modified to apply that agricultural sealant. Correct application rates would require unsafe speeds for standard unmodified asphalt distributors. The equipment must be in good working order and contain no contaminants or dilutants in the tank. Distributor bar tips must be the correct size and must be clean and free of burrs.

Any equipment which is not maintained in full working order, or is proven inadequate to obtain the results prescribed, shall be repaired, or replaced at the direction of the Engineer.

Application of sealer and polymer binder:

Rate of application shall be determined by the texture, porosity, and age of the asphalt pavement to be sealed. The rate of application can vary from 0.010 to 0.020 gallons per square yard. The average rate will generally be 0.015 gallons per square yard. The optimum application rate shall be determined by the owner with the assistance of the contractor's experience. Rates can be adjusted due to surface and environmental conditions.

The material shall not be applied to wet or damp pavement surfaces. Do not apply during rainy or damp weather, or when rain is anticipated within one to two hours after application is completed. Pavement surface temperatures shall be 32 degrees F (0 degrees C), and outside air temperatures shall be 40 degrees F (4 degrees C) and rising. The sealant cure time will need to be adjusted according to ambient and surface temperatures, and humidities.

Traffic shall not be allowed on the roadway surface until the agricultural rejuvenator agent has penetrated and fully cured on the surface. Curing is generally 20-30 minutes with 50 to 80ºF; cooler temperatures will cause the cure time to increase.

No sanding required:

The surface texture of the pavement to be sealed shall be checked prior to application of rejuvenator to verify a good skid value. A pavement with a poor skid value should not be treated with any type of rejuvenator. The sealant and preservation agent will approximately maintain the skid value of the pavement being treated but should not be used on a poor skid value to improve its skid value with this product. Skid resistance testing shall be performed prior to application of sealant if there is a question.

Preparation and cleanup:

The Contractor shall be responsible for sweeping and cleaning of the streets prior to treatment, the street will be cleaned of all standing water, dirt, leaves, foreign materials, etc. This work shall be accomplished by hand-brooming, power-blowing, or other approved methods. If in the opinion of the Engineer the hand cleaning is not sufficient, then a self-propelled street sweeper shall be used. All turnouts, cul-de-sacs, etc., must be cleaned of any material to the satisfaction of the Engineer.

Description of work:

This work shall consist of controlling and maintaining traffic on rejuvenation application projects during the Contractor's operations in the roadway and of providing personnel and equipment for this purpose in accordance with these specifications and as the Public Works Department may require. The work shall include controlling access to the work zone from intersecting roads and adjoining property as may be prudent to ensure the safety of workers and the public and to protect the work and other property. Other traffic-related services may be required in the plans or elsewhere in the Contract.

Standards:

Control of traffic in work zones shall be performed in conformity with this specification and regional DOT standards.

Traffic plan and authorization:

Prior to the start of work, the Contractor shall present a traffic plan to the Public Works Department for approval. In no case shall the Contractor place traffic control devices in the right-of-way, conduct rejuvenation application operations, or otherwise disrupt the normal flow of traffic without properly notifying the Public Works Department and receiving authorization.

Supervisor training:

The Contractor shall assign to the work site at least one employee who is certified as a Worksite Traffic Supervisor by the American Traffic Safety Services Association (ATSSA). A copy of the certificate will be included in the project's Traffic Plan.

Basis of payment:

Payment for the work shall be made at the contract prices or lump sum listed in the Bid Sheet. The contract prices shall be full payment for the work, including all incidental labor and materials necessary for completion of the work and not included in other pay items. Quantities of items to be paid on a unit price basis shall be as called for by the Public Works Department or prescribed in the traffic plan and as measured by the Public Works Inspector.

Unsatisfactory performance:

Substantial omissions or failure by the Contractor in providing the services specified herein shall be cause to immediately shut down the paving operation until the discrepancy or discrepancies have been corrected. The County shall not be liable for any loss the Contractor may incur for mobilization or wasted materials or for any other loss arising from the cessation of work.

Environmental stewardship:

All seals, rejuvenators, and asphalt preservation agents shall be free of harmful materials which will damage the environment during its application, and after it has been applied and is in use. The manufacturer shall certify that their product(s) used to stabilize and preserve the asphalt road surface shall not leach in the presence of moisture, rain, fog, or snow, and shall not contribute toxins or pollute the groundwater runoff after its application. In case of a spill all products shall not harm or otherwise adversely affect the local flora adjacent to the road surface.

Health safety:

The Material Safety Data Sheet (MSDS/SDS) Health section shall assure that the carcinogenicity potential is None.

Substitutions:

The product “RePlay” for the asphalt rejuvenating agent as manufactured by BioSpan Technologies, Inc. is the standard for these Specifications. The prices quoted on the proposal shall be of this standard. Should a bidder wish to submit a bid for an Alternate, said prices shall be entered on the proposal as “Alternate 1”. If the bidder submits no bid for the Standard, only the Alternate should be completed.

Bidders may propose an Alternate for the Standard product specified, provided the bidder adheres to the following and submits it with his bid:

1 This is a “Green” product made from soy oil and agricultural derivatives, and 77% biobased.

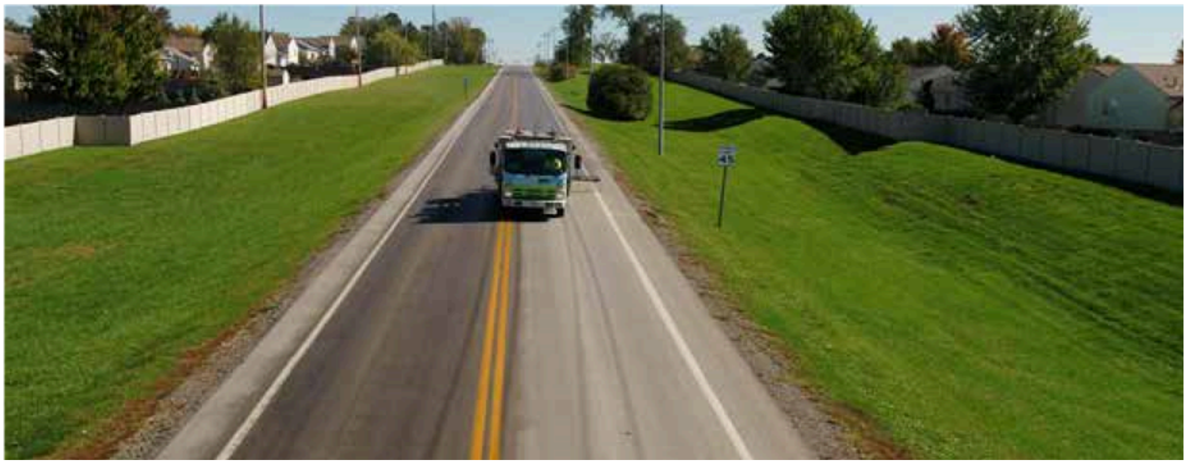
2 The pavement skid resistance shall be maintained because of the material penetrating the pavement, not because abrasive material has been added.

3 List the proposed alternate on the bid sheet form giving the product name and price.

4 Furnish complete specifications and descriptive literature for the alternate as well as a 1-gallon sample of the asphalt rejuvenating agent proposed for use. Such descriptive and detailed information shall be complete and at least equal in detail to the County's requirements for the standard item for which the alternative is offered.

5 Submit a current Material Safety Data Sheet for the alternate product(s).

CONCLUSION



Oxidative aging of asphalt binders can result in the premature failure of flexible pavements. It starts at the time of construction and continues throughout the pavement's life. Oxidation of the asphalt binder causes major detrimental changes to the binder's properties. This paper discussed the many factors that affect aging and the methods that are commonly used to halt or reverse the damaging effect of aging. Traditionally, petroleum (bituminous) based sealers and rejuvenators have been used with various degrees of success, but they all raise environmental concerns.

Environmentally friendly alternatives have recently been engineered, manufactured, and effectively used. BioSpan's RePlay® is a chemically engineered product comprised of soybean oil and agricultural derivatives, and with recycled polymers, that has been in use with great success as a sealer and rejuvenator of asphalt concrete surfaced facilities since 2003. RePlay was designed to reverse oxidation and seal the pavement surface to prevent water and air intrusion that accelerates oxidation. RePlay also makes use of recycled polystyrene to supply the essential SBS and SBBS polymers needed to rejuvenate the asphalt binder to improve the pavement resistance to raveling, rutting, and cracking. When used in preventive maintenance mode, RePlay can add five years to the service life with each application. Besides, unlike petroleum-based products, RePlay is non-toxic, non-polluting, safe for both the users and construction workers, environmentally friendly, and not affected by increasing the price of oil. This paper discussed the many benefits offered by RePlay that improve the performance of asphalt paved surface, including its impact on the environment as a sustainable alternative to traditional petroleum-based products. RePlay has been shown to be not only environmentally safe, but also a product that has a carbon negative footprint that helps in reducing the amount of hazardous greenhouse gases present in the atmosphere.

In conclusion, the use of the agricultural-based rejuvenator and sealer RePlay offers an effective alternative to using petroleum-based products from both economic and environmental standpoints.

ABOUT BIOSPAN

Since 1993, BioSpan's has developed innovative solutions for the world's toughest industries. Our FDA and EPA licensed manufacturing plant in Missouri, USA includes four research and development laboratories.

There, we concentrate on creating new products used for:

- pavement preservation solutions
- crude and heavy oil products
- bio-decontamination
- environmental recovery and resource utilization of solid waste
- cleaners and degreasers

As the number of patents granted on our products grows, we believe that our research-based approach – from the laboratory to the manufacturing plant – makes our solutions effective and affordable. Our products are proven to work under the most demanding, real-world conditions to get the job done, making us a leader in green technologies.

Learn more at www.biospantech.com

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