A Materials Approach to Improving Asphalt Pavement Longitudinal Joint Performance

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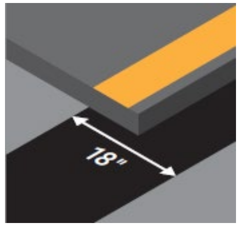
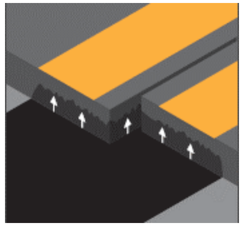
Introduction

- Longitudinal joint performance is key to asphalt pavement performance
- Service life is reduced near the joint up to 36% due to high voids and permeability
- Shortcomings in mechanical methods of improving joint construction led Illinois DOT (IDOT) to the concept of a materials solution: Longitudinal Joint Sealant (LJS)
- Studies of field trials demonstrated the improved performance and life cycle cost benefits, which led to a specification and use of LJS across the highway network

Concept

- A distributor sprays a hot polymer-modified asphalt (not rubber) at a typical width of 18 inches (457 mm) at the planned location of the longitudinal paving joint



- As the hot mix is paved over the LJS and compacted, LJS softens and migrates up into the interconnected voids, making them impermeable to water and air

Original Research

- Bureau of Materials and Physical Research (BMPR) at IDOT reached out to two companies for LJS product
- Goal to fill voids from the bottom-up out to a distance of 9 inches (229 mm) from the joint interface
  - Goal of LJS migration of 50-75% of layer thickness
- Several experimental projects in 2001-2002 were built
- Another goal was to be construction friendly, meaning it could be driven over by construction traffic without picking up
- Projects observed over a decade later

Results of the Research

IL-50, District 1

Control

LJS-1

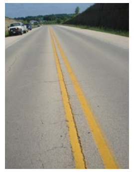
LJS-2


	Control	LJS-1	LJS-2
Permeability* x 10^{-5}, cm/sec	1.5	0	2.5
AC content, %	5.1	7.1	6.7
Air voids, %	10.0	7.9	9.4
Digital image migration, %	-	44	16

IL-26, District 2

Control

LJS-3

LJS-4


	Control	LJS-3	LJS-4
Permeability* x 10^{-5}, cm/sec	372.5	0.2	75.3
AC content, %	5.9	10.3	7.6
Air voids, %	7.6	4.0	6.1
Digital image migration, %	-	65	31
Flexibility Index	0.2	9.0	1.9

US-51, District 7

Control

LJS-5


	Control	LJS-5	LJS-6
Permeability* x 10-5, cm/sec	111	0	0.5
AC content, %	5.1	9.4	10.7
Air voids, %	7.1	3.4	0.4
Digital image migration, %	-	>75	>75
Flexibility Index	0.8	23.3	21.1

Results of the Research, continued

- LJS formulations were adjusted from project to project
- *Permeability was the bottom half of the core

Material Properties and Rates

- Based on the research, a construction and materials specification was developed

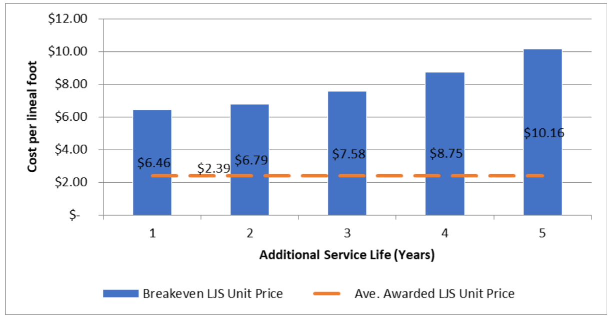
Test	Requirement
DSR (unaged) at 88°C – G*/sind ,kPa	1.0
Creep stiffness (unaged) at -18°C Stiffness (S), MPa m-value	 300 max. 0.300 min.
Ash, %	1 – 4
Elastic recovery, 25°C, %	70 min.
Separation of polymer, diff. in R&B, °C	3 max.

- Stiff at high temperatures
- Flexible at low temperatures
- Unaged – No HMA plant; covered by HMA
- Rates are based on 18-inch (457 mm) width with more values in the paper

Overlay thickness	Coarse mix, lb/ft	Fine mix, lb/ft	SMA, lb/ft
1.5 in. (38 mm)	1.47	0.95	1.26
2.0 in. (50 mm)	1.8	0.95	1.51

Life Cycle Cost Analysis

- Illinois calculates based on a 15-year life cycle
- Average awarded LJS price was $2.39 / linear foot (2020)
- Break-even price of $6.46 for one-year added life (year 16)
- Life extension of joint experienced to date is 3 to 5 years



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ABSTRACT

Many states are looking for methods to improve longitudinal joint performance of their asphalt pavements since these joints often fail before the rest of the surface. With their inherently lower density, longitudinal joints fail by cracking, raveling and potholing because of the intrusion of air and water. Due to their longitudinal joint issues, and after trying several less-than-successful traditional solutions, the Illinois Department of Transportation (IDOT) developed a concept to seal the longitudinal joint region, but from the bottom up. Test sections were constructed in 2001 through 2003 to determine how a newly developed material, called longitudinal joint sealant (LJS), would improve joint performance. LJS is a highly-polymer-modified asphalt cement with fillers and is placed at the location of a longitudinal joint prior to paving. As mix is paved over it, the LJS melts and migrates up into voids in the low-density mix, making the mix impermeable to moisture while sealing the longitudinal joint itself. The IDOT test pavements were evaluated after twelve years and found to have longitudinal joints that exhibited significantly better performance than the control joint sections and were in similar or better condition than the rest of the pavement. Laboratory testing of cores showed decreased permeability and increased crack resistance of mix near joints with LJS as compared to similar mix without LJS. The life extension of the joint area is approximately three to five years, and the benefit is calculated to be three to five times the initial cost.

Keywords: Longitudinal joint, longitudinal joint sealant (LJS), void reducing asphalt membrane (VRAM)

INTRODUCTION

Longitudinal joint performance has been recognized as being important in the overall quality of hot-mix asphalt (HMA) pavement (*1*) and to pavement life (*2*). A 2012 report by the Asphalt Institute on best practices for constructing longitudinal joints stated that improving joint performance is "probably the single most important thing to improving asphalt pavement performance" (*3*). To obtain good performance, proper longitudinal joint construction practices, including obtaining higher density, is critical. A study by Washington State Department of Transportation on the effect of compaction on HMA found that the percent loss in service life from seven percent voids to ten percent voids is 17 percent and drops to 36 percent loss at twelve percent voids (*4*). Clearly, high voids (low density) has a negative effect on the performance of the pavement and joint. High void content mixes have higher permeability, which the state of Kentucky recognized as accelerating pavement deterioration through de-bonding of asphalt layers and asphalt stripping (*5*). Joint performance issues have led to many studies on best construction techniques and mechanical solutions to solving the problem. Paving techniques, such as paving wide and trimming off the mat edges prior to placing the adjacent lift, constructing wedge joints, and heating the unconfined joint have been tried. Rolling techniques like rolling from the hot side or cold side or using an edge-restraining device have been studied. Several of these mechanical techniques are looked at in this paper. Shortcomings in all the mechanical solutions led the Illinois DOT (IDOT) to consider a materials solution to this longitudinal joint performance problem, which is the main topic of this paper. Successful field trials and studies of a material named longitudinal joint sealant (LJS) showed much improvement in joint performance, and the technical and life cycle cost analysis results are discussed.

JOINT QUALITY DURING CONSTRUCTION

The two most common methods of measuring joint quality during construction are density and permeability. Density is by far the more common method since it is typically used to determine if the compaction efforts resulted in the mat meeting contract specifications. Permeability has been used in special studies.

Improving Joint Density and Challenges

While it is desired to have the density of the mix at joints matching the density of the mix across the mat for uniform performance, it is extremely difficult to obtain. One reason is that typically the mat edges of a first paver pass are unconfined and the mix tends to move laterally since there is nothing to compact against. Lateral movement may also result from a poor bond due to inadequate or insufficient tack coat and results in lower mix density. Sufficient joint density is not just a problem for an unconfined mat edge. While the mixture on the second paver pass (often referred to as the hot side of the joint) is typically easier to achieve compaction due to confinement, there is potential for problems here, too. Hot side paving also applies to mill and inlay projects. There is potential for the contractor to incorrectly position the screed to obtain a smooth, matching joint with the adjacent cold lane that does not account for proper roll-down of the mix. Additional density from a steel wheeled roller cannot be obtained once the thickness of the hot side is matched with the cold side; with the use of a pneumatic-tired roller, the material will be compacted more but then the joint surfaces do not match. Other items of importance for obtaining density in the second paver pass include pushing the HMA tightly against the previous lane by position of the paver and auger and eliminating segregation at the edge of the screed with proper auger extension, maintaining material height in the auger box, and setting the speed of the paver so that the outer edges of the screed aren't starved for material (*2*).

The National Road Research Alliance (NRRA) worked with five states to determine what longitudinal joint density should be – or at least what is achievable - to obtain better performance. Their paper states that as HMA density decreases, air voids are more interconnected which leads to more moisture intrusion and freeze-thaw damage, causing the longitudinal joints to ravel over time. Required density values at the edge of the mat ranged from 88.1 to 94 percent, with lower requirements at the unconfined edge (88.1 to 92 percent) and higher requirements at the confined edge (89.5 to 94 percent) (*6*).

A study by Cross and Bhusal for Oklahoma DOT found that a well-constructed longitudinal joint should have a density within two percent of the mat in the same vicinity. However, they also found that there is normally a steep density gradient from the joint extending six inches into the mat (*7*), with more than a two percent difference.

Decreasing Permeability

Increasing density will lower water permeability which should lead to improved joint performance. As stated by Cooley et al. (*8*), a permeable pavement allows water to permeate the void structure which leads to moisture-induced damage, while air penetrating into a pavement can lead to excessive age hardening of the binder and, thus, premature cracking. A study for PennDOT (*9*) by Solaimanian found that for 12.5-mm nominal maximum aggregate size (NMAS) mixes, permeability increases drastically when in-place air voids are above approximately seven to eight percent; for 9.5-mm NMAS mixes, the value is eight percent. A field permeability limit of 1.5×10^{-3} cm/second was suggested. A separate study by Cooley et al. (*10*) found a critical field permeability limit of 1.0×10^{-3} cm/second for Superpave coarse-graded mixtures, corresponding to 92.3 percent density. Furthermore, in the Cross and Bhusal paper previously referenced (*7*), Oklahoma DOT mixes, which are fine-graded, have a relationship between in-place air voids and permeability that shows permeability begins to increase when in-place voids exceed 8 percent and increases drastically when voids exceed 10 percent. The critical void contents, where permeability shows a marked increase, occur at approximately 10 and 12 percent voids (88 and 90 percent compaction). While permeability is a more direct measurement of water penetrating voids and its potential of causing long-term problems, it is not a practical field control tool. The correlations with air voids are useful but show that the critical void content to limit water intrusion and therefore long-term problems is not always achieved or specified (i.e. NRRA findings).

Other Methods to Improve Density and Joint Performance

In addition to some of the paving practices previously discussed to improve joint density, there are other practices that improve joint quality, such as ensuring that the edge of the mat is straight and having the steel wheel roller overhang the edge of mat by six inches (*6*).

There are other methods that may improve joint performance. Among them are echelon and full-width paving. With full-width paving, there is no centerline joint. In the case of echelon paving, one paver is used to place a mix in a lane while a second paver is used in the adjacent lane with the two pavers usually located within 30 feet of each other. In both cases, both lanes and joint are rolled simultaneously without the effects of an unconfined joint. However, there are often space constraints that limit the practice to airfields or where two adjacent lanes of a roadway can be shut down. It may not be practical for other reasons, such as the pavers' speed being limited by plant capacity. Another practice used on airfields or where space constraints allow is cutting back the lower density unconfined edge (*2*). In this practice, the edge is cut back up to six inches using a cutting wheel prior to placing the adjacent lane.

Joint shape may affect performance. The very common butt joint is mostly vertical and is formed by the end plate of the screed on the first paver pass (unconfined). To improve joint quality and safety for the motoring public during the construction process, several states have used notched-wedge joints when the thickness of the mat is more than 2 inches. The wedge is created by a form placed on the paving screed for shaping the notch and wedge during paving of the first lane. The notched wedge may be slightly different in various specifications but in general is a vertical notch of 0.75 to 1-inch depth is at the top, tapers about 12 inches in width, and connects with another 3/8-inch to 0.75-inch notch, or no notch, to the top of the underlying mat; this is sometimes called a Michigan wedge. A New Jersey wedge is different in that it has no notches and slopes 3:1 over a nine-inch width. A wedge helps restrain lateral movement of the mat during rolling, resulting in increased density and decreased permeability. In a Connecticut DOT study, butt joints were compared to Michigan notched-wedge joints. Their findings from cores from two projects showed that the notched-wedge joint provides a higher level of density on the cold side of the joint than the butt joint. The inverse was true for the hot side of the joint, with the butt joint having a higher density on the two projects. Across a 24-inch width centered at the joint, the notched-wedge joint had more uniform density than the butt joint on both projects. Between the two projects, the density values for the notched-wedge joint in the referenced 24-inch width ranged from 88.5 to 90.3 percent of theoretical maximum density, and the butt joint sections ranged from 85.6 to 91.2 percent (*11*). Though notched-wedge joints have been shown to improve the density overall at the joint, comparing the results with other studies still leaves concern that resulting air voids will result in detrimental permeability.

Another approach that has been used to try to improve joints is to apply a sealant on the vertical face of the butt joint during construction; this can also be applied at transverse joints. The sealant can waterproof the joint even though density may not be improved. Rubberized asphalt has often been used to seal joints during the construction process and is applied with a heating kettle and hand wand. Improved performance of the joint has been noted (*5*). An NCAT study on different techniques in Pennsylvania showed using a rubberized joint material gave the best performance of eight treatments after six years (*12*). Some agencies allow the project tack coat to be used on the face of the joints. Both a sealant and tack have been used on notched-wedge joints. A Kentucky study investigated longitudinal joint compaction and techniques for improved density values at longitudinal joints and found that joint adhesives applied (manually) to the vertical face of the joint showed good performance and performed better than the projects constructed without joint adhesives (*5*). A study for the Arkansas State Highway and Transportation Department (now the Arkansas Department of Transportation) investigated eight techniques, among them joint sealants, to maximize longitudinal joint performance (*13*). A joint adhesive was placed manually, and a tack coat was sprayed by a distributor on the vertical longitudinal joint. Though intended to seal the joint, the researchers found that permeability was reduced in a finite area but not in the surrounding material. Obtaining low permeability was considered the method for obtaining good joint performance. The sealants discussed in these papers were applied only at the joint interface and did not show any appreciable effect a short distance away from the joint where the permeability was still high.

RESEARCH OF LONGITUDINAL JOINT SEALANT BY IDOT

Prior to 2000, the Illinois Department of Transportation (IDOT) had experimented with several of the different longitudinal joint construction techniques mentioned above in attempt to improve joint density, but none of them increased density enough to reduce permeability to the level needed to substantially improve joint performance. Since the necessary level of density was not achievable, IDOT decided to try a different approach of filling the high level of interconnected in-place air voids with polymer-modified asphalt binder. In 2001, after a long history of poor performing longitudinal joints driving pavement rehabilitation in Illinois, IDOT began experimenting with paving over short sample sections of a preformed, over-band crack filler in an attempt to seal the longitudinal joint low-density region from the bottom up. An 18-inch-wide band of this material was placed on the roadway prior to paving the surface course, centered where the longitudinal joint of the surface would be. The first pass was paved over it, thus covering half the width of the band, and the second paving pass in the adjacent lane covered the other half. The 18-inch width of the band was selected based on an extensive evaluation of longitudinal joints of various mix types statewide looking at permeability and density at the joint and incremental distances from the joint. It was determined that the pavement density remains low, and permeability remains extremely high, on unconfined edges up to nine inches from the joint interface. While the sample sections of preformed, over-band material worked well in restraining the unconfined edge during the rolling process and was stiff enough to allow construction traffic to drive over it without sticking and picking up, it was too stiff to allow it to melt and migrate upward into the surface course to an appreciable level. This prompted IDOT’s Central Bureau of Materials and Physical Research (BMPR) to reach out to two companies to develop the materials and application methods for a product that could be driven over with minimal pickup, yet able to melt and migrate to the target level of 50 to 75 percent of the pavement layer thickness. The BMPR tested various formulations from each company for migration by placing a 3/16-inch-thick application of each trial formulation onto the top of a pre-compacted gyratory specimen. The room-temperature specimen was placed in a gyratory mold; loose preheated surface mix was added on top of the trial formulation and then the mix was compacted to achieve density in the 93 ± 1 percent range. The 1.5-inch-thick compacted surface specimen was sawn off the pre-compacted specimen and then broken in half vertically to visually inspect the level of migration. Once formulations achieving the desired level of migration were developed by both companies, experimental construction projects were set up with test sections for both longitudinal joint sealant (LJS) products and a control section.

Immediately following construction, permeability testing was performed on all sections using a three-stage falling head field permeameter at the joint and at incremental locations moving away from the joint on either side. Permeability was also measured in the laboratory on cores taken from the joint region using a falling head permeameter that measures vertical flow only. The vertical permeability of the cores from the LJS sections for both products was zero, indicating that water cannot penetrate the pavement structure below the surface course. For both products, the in-place permeability in most cases was reduced by roughly half of that in the control section. Where the migration level was at 50 percent, the top half of the surface course remained permeable and allowed horizontal flow in the top half of the surface course (*14*) (*15*).

The experimental projects were visually evaluated over a decade after they were constructed. As can be observed in **Figure 1** and **Figure 2**, there was a stark difference in visual performance between the LJS and control sections in the 12 plus year old pavements. In some of these sections, the center 18 inches was outperforming the rest of the pavement on either side. In other sections the center 18 inches was performing similar to the pavement on either side. The photos represent sections containing LJS products from both companies on the same project. Most of this project did not contain LJS which resulted in a severely deteriorating centerline joint, which prompted the district's maintenance crew to route and seal the entire project. They inadvertently routed and sealed the experimental LJS sections as can be observed by the black stripe. The black circular blemishes in **Figure 1** on the centerline are residual rings of silicone from the permeability testing conducted 12 years earlier.

Figure 1 Twelve-year old pavement evaluation of LJS

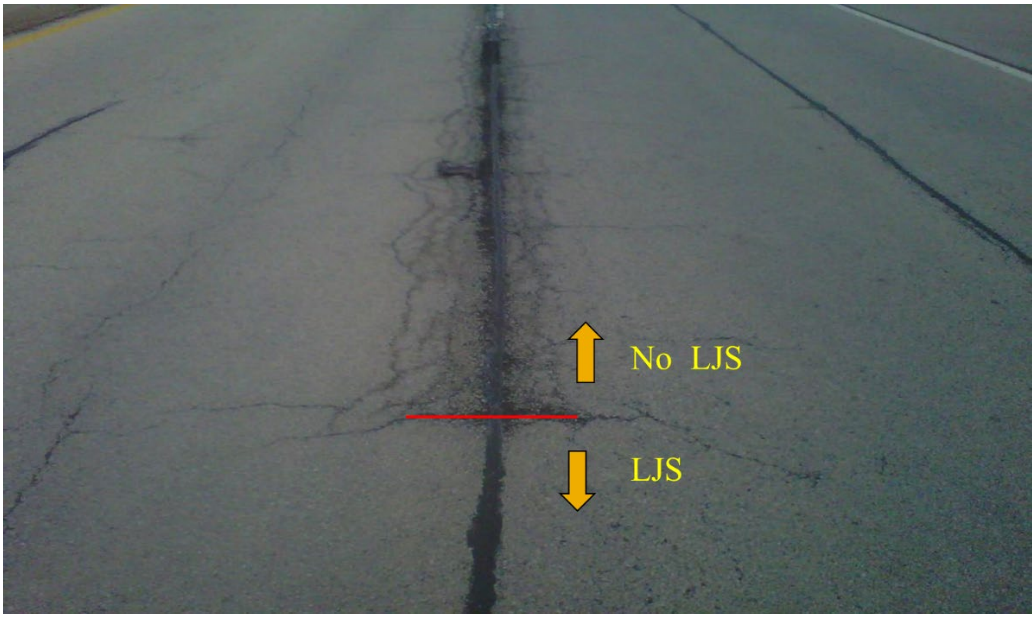

Figure 2 LJS and non-LJS under centerline of twelve-year-old pavement

In 2017, three of the original experimental sections that were constructed between 2001 and 2003 were evaluated by the IDOT Central Bureau of Materials (CBM). Permeability was first tested in-place using a three stage falling head permeameter. Cores were then taken for laboratory testing of bulk specific gravity, asphalt binder content, Illinois Flexibility Index Test (I-FIT), laboratory permeability and level of migration using digital image analysis (DIA). Additional cores were cut at mid-height to identify differences in permeability, asphalt binder content, and density from the bottom half and the top half. Using the measured asphalt contents of the whole core and core halves and the production effective specific gravity of the asphalt mixture, the maximum specific gravity (G_{mm}) was backcalculated for the whole core and the top and bottom halves individually. This allowed the density, which is based as a percent of G_{mm}, to be determined accurately in the whole core and each core half.

From this analysis it was determined that the whole core density in the LJS test sections averaged 3 percent higher density than the control sections. The density of the top half of the cores for the LJS sections ranged from the same to 2 percent higher density than the control sections. The density in the bottom half of the cores for the LJS sections averaged 5 percent higher than the control sections. While the field permeameter was run on the roadway on the various sections, it did not provide meaningful information since road debris plugged the surface to the extent that all the sections had very low permeability. This was verified with the laboratory permeability testing. While the top half of all the cores, including the control sections, had low permeabilities in the range of 20 to 30 x 10^{-5} cm/sec, the bottom half of the control section cores had permeabilities that typically ranged from 110 to 372 x 10^{-5} cm/sec. The permeability for the bottom half of the LJS cores was zero in all cases. The asphalt content in the top half of the LJS cores ranged from 2 to 12 percent higher than the control section and averaged 7 percent higher in the whole core, while the asphalt content for the bottom half of the LJS cores ranged from 70 to 180 percent higher than the control section and averaged 122 percent higher. The asphalt content for the whole LJS core is typically double that of the control section. Digital images were taken of the whole core cut faces using a high pixel camera. DIA was performed on the digital images for each of the LJS sections to determine the level of the LJS migration. The migration levels ranged from 10 mm to 25 mm, which was 26 to 66 percent of the surface course thickness. It should be noted that current formulations and applications of LJS are resulting in higher levels of migration more consistently in the 50 to 75 percent range. Cracking susceptibility was also evaluated on two of the projects using Illinois' I-FIT cracking test (AASHTO TP 124) to determine the Flexibility Index (FI). IDOT requires newly placed HMA that is plant produced and lab compacted to have an FI ≥ 8.0 and will soon require Long Term Aged (LTA) HMA to meet an FI ≥ 4.0. For these now 15-year-old pavements that were cored to produce direct test samples, the FI results for one of the projects was 0.2 for the control section, 1.9 for one LJS product section and 9.0 for the other LJS product section. The second project had an FI value 0.8 for the control section, 21.1 for one LJS product section and 23.3 for the other LJS product section.

Overall, it was found that LJS lowers permeability by increasing the asphalt content, resulting in an increased FI, which is an indicator of crack resistance. The improved field crack resistance was observed in the twelve-year old pavement test sections.

MATERIAL PROPERTIES

The current Illinois DOT LJS material specification resulted from the work in Illinois, with other states following with similar material property requirements. LJS is also known as void reducing asphalt membrane (VRAM) by some other states. Table 1 shows the requirements for LJS in Illinois. Elastomers are used to modify the base asphalt and are either a styrene-butadiene diblock or triblock copolymer without oil extension or are styrene-butadiene rubber. The current IDOT practice is to only allow approved modifiers. Modifiers, such as air blown asphalt and acid modification, are two examples that are not allowed.

TABLE 1 Illinois DOT LJS materials specification

TEST	REQUIREMENT	TEST METHOD
Dynamic shear @ 88°C (unaged), G*/sin δ, kPa	1.00 min.	AASHTO T 315
Creep stiffness @ -18°C (unaged) Stiffness (S), MPa m-value	 300 max. 0.300 min.	AASHTO T 313
Ash, %	1.0 - 4.0	AASHTO T 111
Elastic Recovery, 100 mm elongation, cut immed., 25°C, %	70 min.	ASTM D6084 (A)
Separation of Polymer, difference in ring and ball, °C	3 max.	ASTM D7173

An adequately stiff binder must be used to prevent pickup by the paving equipment and to prevent creating a tender mix around the LJS placement. A minimum dynamic shear, G*/sin δ at 88°C based on unaged properties, has been used and proven to perform successfully. The grading is performed on unaged binder because the LJS is handled hot and in bulk and is placed in thick films that cool quickly on the road. The LJS is never exposed to high heat and thin films as typical with HMA mixes produced through a hot mix plant.

While the LJS must be stiff at high temperatures, it must be flexible at low temperatures to prevent cracking issues. In the Illinois area, where LJS was developed, a creep stiffness at -18°C on unaged binder properties is used, which equates to a -28-grade material. Most HMA binders in Illinois are a -28 grading on aged binder for the surface mix. The LJS grading of -28 on unaged binder maintains at least equivalent or better low temperature performance compared to the binder in the mix. With the LJS binder properties plus the increased amount of total binder in the joint area of the mix from the addition of LJS, the resistance to cracking is increased.

The LJS meets the high temperature and low temperature properties primarily from polymer modification. A separation test is required with a maximum of 3°C difference in ring and ball softening point between top and bottom samples from the separation tube. The elastic recovery test, with a minimum requirement of 70 percent, is used as an identifier of elastomeric polymer properties.

An important property related to placement of LJS on the road is resistance to flow. For the air voids to be filled in the area of the joint, an adequate amount of LJS must be present. As polymer content increases in LJS, the resistance to flow increases. However, as the polymer content increases, the minimum temperatures for placement also increases. It was determined that a small amount of inert filler helped to reduce flow characteristics without requiring additional temperature for placement. The specification addresses the flow resistance by the requirement of 1.0 to 4.0 percent ash content.

Through experience, the application rates for LJS have been found to be dependent upon the type of mixture being placed and the target thickness of the final compacted overlay. Rates have been established for coarse-graded HMA, fine-graded HMA, SMA and SuperPave5 (*16*) mixtures and are given in pounds per lineal foot for an 18-inch width (**Table 2**). SuperPave 5 mixes are used by the Indiana Department of Transportation (InDOT).

TABLE 2 LJS Application Rates for an 18-inch Wide Strip

Overlay Thickness Inch (mm)	Coarse-Graded lb/ft (kg/m)	Fine-Graded lb/ft (kg/m)	SMA/SuperPave5 lb/ft (kg/m)
¾ (19)	0.88 (1.31)		
1 (25)	1.15 (1.71)		
1 ¼ (32)	1.31 (1.95)	0.88 (1.31)	
1 ½ (38)	1.47 (2.19)	0.95 (1.42)	1.26 (1.88)
1 ¾ (44)	1.63 (2.43)	1.03 (1.54)	1.38 (2.06)
2 (50)	1.80 (2.68)	1.11 (1.65)	1.51 (2.25)
≥ 2 ¼ (60)	1.96 (2.92)		

The highest table rates are for coarse-graded HMA. SMA rates are the next highest and fine-graded HMA mixes are the lowest rates. LJS in SuperPave5 mixtures acts most like SMA mixture void content at the joint and those rates are being used in current SuperPave5 design projects.

The distribution of the total asphalt is a gradient, with the highest asphalt content at the interface of the existing surface and the new overlay and progressively decreasing up to 50 to 75 percent of the height of the new overlay. The addition of LJS, an unaged, polymer modified binder, in sufficient quantity to fill a high percentage of voids in the new HMA, creates a highly flexible, crack resistant mixture. The void filling characteristic of the LJS also creates an impermeable barrier to water penetrating the HMA layers below the overlay.

CONSTRUCTION PROCESS FOR LJS

The LJS application operation fits into the daily paving operation as easily as the distributor applying tack coat does due to the quick cooling of the hot-applied material. A heavy-duty pressure distributor with the ability to heat and spray hot asphalt is the most commonly used equipment to apply LJS (**Figure 3**). The distributor must have heating, recirculation, and agitation systems to maintain heat uniformity. The temperature typically does not exceed 320°F. A method to apply the product at the prescribed rate and widths at the location of the longitudinal joint is required. On smaller projects, a portable melting kettle pulled by a truck with either a spray bar or a feed wand with an applicator shoe has been used.

Figure 3 Heated pressure distributor and LJS spray bar

Prior to spraying, any defects in the area to be sprayed, such as depressions, potholes, or wide cracks, should be corrected by patching or sealing. Just prior to spraying, the pavement must be clean and free of debris and must also be substantially dry to get proper bonding to the substrate. If an emulsion tack is applied before LJS, the tack must be fully cured. A string line or paint marks are applied to the substrate and must be followed during spraying to ensure proper location of the LJS.

The center of the applied LJS is required to be within 1.5-inch of the prescribed location and should not flow more than two inches. A rate check is performed periodically on the project with roofing felt and a portable balance, with a yield check performed by obtaining before and after weights on the distributor and measuring the length sprayed. On mill and fill projects, the spray width is reduced by half to nine inches, with more attention given to cleaning that area and ensuring it is dry before spraying. It has been found that after the LJS is applied, it may have traffic cross it once the surface temperature of the LJS is 130°F or below. Specifications require that the LJS be suitable for construction traffic to drive across it within 30 minutes of placement without pickup or tracking, though it is generally three to ten minutes or when the temperature of the product has reached 130°F.

In the paving operation, the screed extension end plate and physical contact grade control devices are raised or adjusted so that they are not in contact with the LJS. Other than crossing it, trucks and paving equipment should not drive or stop on the LJS. The rolling operation does not change. The increased total asphalt content in the area of the longitudinal joint makes testing joint density with a non-destructive density gauge inaccurate due to a substantial change in the mixture maximum specific gravity. As a result, IDOT waives density measurements for one foot on either side of the joint.

COSTS AND LIFE-CYCLE COSTS

Life cycle cost analysis (LCCA) is a tool to evaluate the effectiveness of a construction method or alternative treatment. After years of effective service, IDOT looked at the benefits that LJS was providing. Using a modified version of IDOT's existing framework for pavement selection type using LCCA, an analysis was performed to determine the cost benefit that LJS was providing over the life span of an HMA overlay. IDOT's LCCA framework can be found in Chapter 54 of the Illinois Department of Transportation Bureau of Design and Environment Manual (*17*).

It has been IDOT's experience to receive approximately 15 years of service for a first generation HMA overlay on either full-depth HMA or Portland cement concrete pavements. This experience is reflected in the life cycle models and is the baseline that was used for comparison. **Figure 4** depicts the existing LCCA framework has maintenance activities prescribed at five-year intervals. The joint route and seal includes both the centerline joint and the shoulder joints.

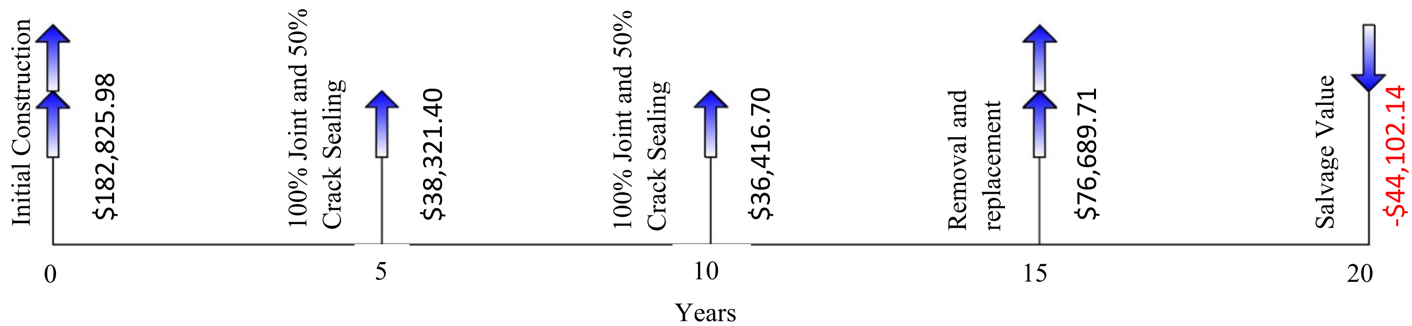

Figure 4 LCCA Life Cycle Model for HMA Overlay

Before discussing the modifications to the LCCA framework and the results of the analysis, the assumptions made for this analysis need to be covered. IDOT's current LCCA framework utilizes a discount rate of 3%. For this study it was assumed that the project was 1 mile in length, and it was a typical state route consisting of two lanes. It is also using a two-lift overlay (binder course and surface course) in this scenario, thus only placing one lift of LJS under the surface course. It has been IDOT's practice that the contractor retains the reclaimed asphalt pavement so the salvage value will be zero. IDOT's policy on state routes is to mill off the surface course and then place the subsequent required overlay at the end of the original overlay's life.

Initial construction materials included tack coat, IL 9.5 mm surface mix (N50) at 1.5 inches, one lift of LJS, and IL 9.5-mm fine graded binder mix (N50) at 1.25 inches. All the unit prices for these materials came from IDOT's awarded unit price database, Pay Estimates System (PES). The prices are the statewide averages over the past five years.

As seen in **Figure 5**, maintenance activities for the scenario with LJS have been pushed back to account for the extended life and the performance benefits of the material. Additionally, the centerline joint route and seal for the section with LJS was removed. The initial data indicated the life extension achieved when adding LJS is approximately three to five years.

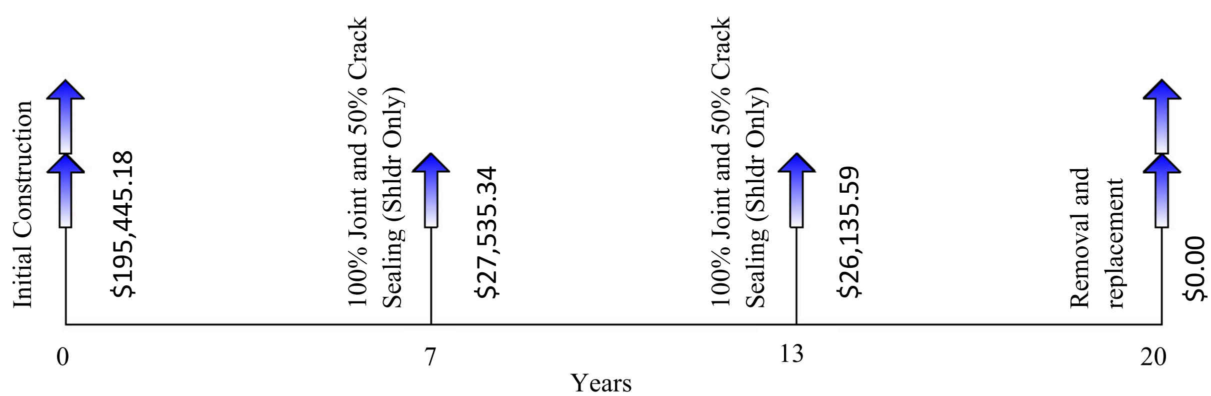

Figure 5 LCCA Life Cycle Model for HMA Overlay with LJS

The annual cost of both scenarios was calculated for years 16-20 using **Equation 1**. IDOT's existing procedures do not include the annual administrative, overhead, and maintenance cost. Those factors are assumed to be equal for all pavement types.

$$A = CRF_n(C + \sum_{n=1}^{N} R_n(PWF_n)) \qquad (1)$$

A	=	*total annual cost per mile*
CRF_n	=	*capital recovery factor for year n*
C	=	*Initial construction costs*
R_n	=	*n^{th} rehabilitation cost per mile*
PWF_n	=	*present worth factor for the n^{th} number of years after the initial construction that the n^{th} rehabilitation activity is performed.*

The difference of these values was compared to calculate the annual savings. The net present values for each scenario were calculated and the net present value savings were calculated. The results can be found in **Table 3**.

TABLE 3 Life Cycle Cost Analysis Results

Year - n	A - LJS	A - No LJS	Annual Savings	NPV - LJS	NPV - No LJS	Net Present Savings
20	$16,744.42	$19,502.75	$2,758.33	$249,116.12	$290,151.64	$41,035.52

To further quantify the benefits of LJS, the cost to break even in performance was calculated using **Equation 2** and then compared to the average awarded price of LJS from January 2018 to April 2020.

$$\frac{\left(NPV_{NS} - (NPV_{LJS} - LJS)\right)}{5280} = BEP \qquad (2)$$

NPV_{NS} = Net Present Value of one mile without LJS
NPV_{LJS} = Net Present Value of one mile with LJS
LJS = average awarded price of one mile of LJS
BEP = break even cost

To better understand the benefit of the LJS material, IDOT used the difference in net present values of the section without LJS and the section constructed with LJS minus the cost of LJS. Taking that value and dividing by 5,280 gives the cost benefit of this construction practice in similar units to the average awarded price of $2.39 per linear foot. This was initially completed for the 20-year analysis but was repeated for 16, 17, 18, and 19-year analyses to better understand the progression of the results. The results are shown in **Figure 6** and clearly show the benefit of LJS. The benefit of this construction practice is three to five times the cost of the material. This LCCA has shown the benefits of LJS in many ways.

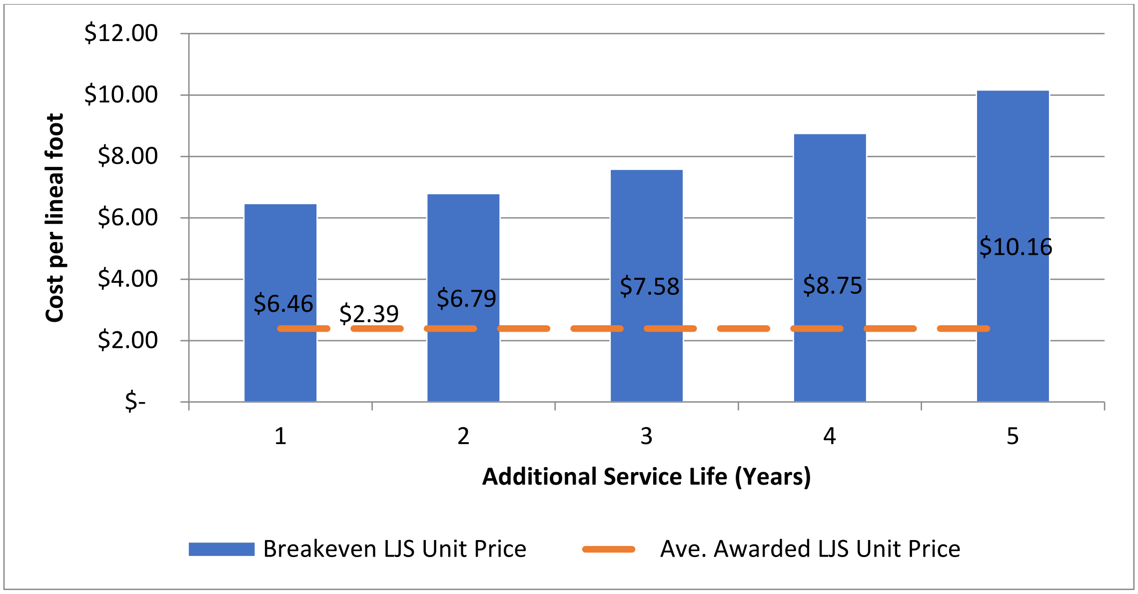

Figure 6 Cost Benefit per Two-Lane Mile of LJS with Different Overlay Service Lives

SUMMARY AND CONCLUSIONS

Many approaches to improving the performance of asphalt pavement longitudinal joints have been tried by various agencies with mixed or marginal success. IDOT looked at a bottom-up material approach to seal the voids in the lower-density longitudinal joint area, with the result being lower permeability and an improvement in predicted laboratory flexibility and field performance. The high polymer LJS material has rut resistant and crack resistant binder properties and has been easily imbedded into the construction process of surface courses. The life extension of the joint area is approximately three to five year, and the benefit is calculated to be three to five times the initial cost.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Jim Trepanier; data collection: Jim Trepanier and John Senger; analysis and interpretation of results: Jim Trepanier and John Senger; draft manuscript preparation: Todd Thomas and Marvin Exline. All authors reviewed the results and approved the final version of the manuscript.

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