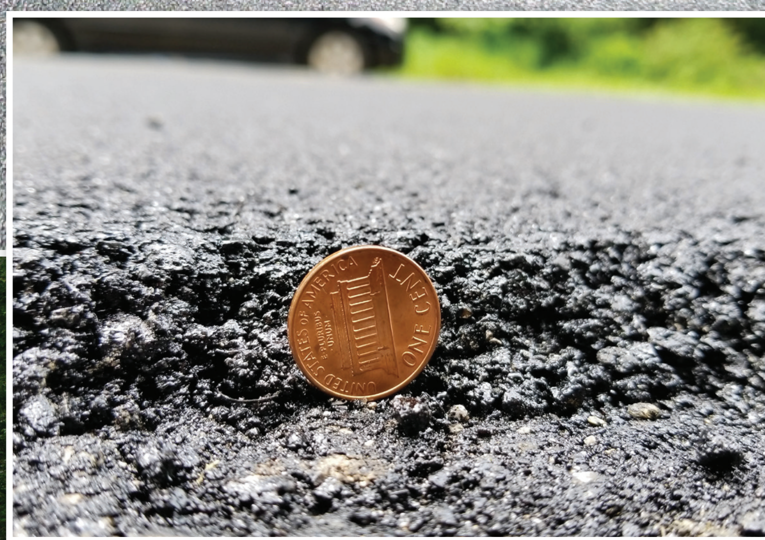
Information Series 141

NATIONAL ASPHALT PAVEMENT ASSOCIATION

Thinlays for Pavement Preservation



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Thinlays for Pavement Preservation

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16. Abstract

The asphalt paving industry has successfully developed and utilized a suite of thin asphalt pavement mixtures — called Thinlays™ — for pavement preservation. These thin pavements can be placed in thicknesses as little as ⅝ inch. Thinlays provide a number of benefits when compared to other pavement preservation techniques, including increased life, decreased life-cycle costs, improved ride, and decreased noise.

Experience shows Thinlays to provide excellent performance when placed on asphalt pavements that are in good to fair condition. Pavements whose condition has deteriorated beyond fair condition are not suitable for Thinlays as a means of pavement preservation.

Though sometimes referred to by other names, Thinlays have been widely used for pavement preservation, and have often proved to be the preferred preservation treatment because of their many benefits.

This guide provides comprehensive guidance on using Thinlays for pavement preservation — including how Thinlays fit within pavement management systems, when and how they should be used based on existing pavement condition, how Thinlay mixes should be developed and specified, and best practices for Thinlay construction. This guide also helps users compare the cost and performance of common pavement preservation techniques.

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On the Cover

Main Cover Image: A ¾-inch Thinlay placed by J.D. Ramming Paving Co. Ltd.

Lower Left: A Thinlay being placed on a Kentucky road.
Lower Right: A Thinlay compacted to a thickness of less than ¾-inch, about the height of a penny.

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Executive Summary

Limited infrastructure funding at the local, state, and federal levels has resulted in greater emphasis on the use of pavement preservation techniques to prolong pavement life and reduce maintenance costs.

The asphalt paving industry has successfully developed and utilized a suite of thin asphalt pavement mixtures — called Thinlays™ — for pavement preservation. These thin pavements can be placed in thicknesses as little as ⅝ inch.

Thinlays provide a number of benefits when compared to other pavement preservation techniques, including increased life, decreased life-cycle costs, improved ride, and decreased noise.

Experience shows Thinlays to provide excellent performance when placed on asphalt pavements that are in good to fair condition. Pavements whose condition has deteriorated beyond fair condition are not suitable for Thinlays as a means of pavement preservation.

Though sometimes referred to by other names, Thinlays have been widely used for pavement preservation, and have often proved to be the preferred preservation treatment because of their many benefits.

This guide provides comprehensive guidance on using Thinlays for pavement preservation — including how Thinlays fit within pavement management systems, when and how they should be used based on existing pavement condition, how Thinlay mixes should be developed and specified, and best practices for Thinlay construction.

This guide also helps users compare the cost and performance of common pavement preservation techniques.

A Thinlay on RM 12 in Dripping Springs, Texas, helped significantly reduce road noise while also improving surface friction and thus safety.

1 Introduction

With limited funding and aging roads, pavement managers need preservation treatments that will improve the driving surface, protect the underlying pavement structure, and extend the pavement's service life. The Federal Highway Administration (FHWA) describes pavement preservation as a critical component of an agency's asset management plan (Waidelich Jr., 2016).

Thinlays were developed specifically for pavement preservation using proven pavement design principles, and they share many of the same benefits of thicker asphalt pavement applications — including improved smoothness, crack reduction or elimination, noise reduction, and the pleasing appearance of a new surface. Early Thinlays that were properly designed and constructed have performed excellently for more than 10 years, almost double the expected life of other preservation treatments.

Thinlays are a new generation of dense-graded, thin-lift asphalt pavements designed to last, be crack resistant, and be placed thinner than any other asphalt pavement (Figure 1). Thinlay mixes provide a tight, water-resistant surface, and, because Thinlays use smaller aggregate, they can be constructed to provide smoother transitions from existing or milled surfaces.

Agencies that have used Thinlays for pavement preservation have discovered that Thinlays are reliable and cost-effective. Like every other preservation treatment, however, Thinlays are not a cure for failed pavements. With proper application to pavements in good or fair condition, Thinlays provide pavement managers a way to greatly extend the life of existing pavements and eliminate the need for repeated short-term treatments.

This guide is intended to help engineers, managers and contractors successfully use Thinlays, and will address:

- The benefits of Thinlays
- Where and when to use Thinlays
- How to design and specify Thinlays
- Construction and quality control best practices for Thinlays
- Performance measures for Thinlays

This guide does not address all the types of asphalt pavement mixes that may be considered "Thinlays" in specific areas of the country. For example, open-graded friction courses (OGFC) are commonly used in regions without significant studded tire use, and they can be placed as thin as Thinlays. Similarly, stone-matrix asphalt (SMA) mixtures have been used in some regions for thin overlays. OGFC and SMA mixes, like some of the other mix types that can be placed thin, have separate guidance documents that address regional issues.

This guide focuses on dense-graded Thinlay mixes because their application is universal.

Figure 1. Dense Thinlay surface before compaction

A compactor closely follows the paver on a demonstration Thinlay project in Nashville.

2

Thinlay Benefits

Because Thinlays provide a new asphalt pavement surface, they improve things that the traveling public cares about: smoothness, safety, and noise. They also improve the things pavement managers care about: service life, structure, and impermeability. No other common preservation treatment provides all the benefits of Thinlays.

Thinlay benefits include:

- Extended service life
- Protection from water damage
- Improved structural strength
- Improved ride quality
- Improved drainage
- Reduced noise
- Elimination of curing and binder runoff
- Sustainability through reduced fuel use and the use of recycled materials
- Controlled production process
- Locally available experience
- Preferred by cyclists and pedestrians

These benefits will be discussed in more detail in this section.

Extended Service Life

Pavement service life — the length of time a pavement can provide a specified level of service — is critical to pavement management. The goal for road investments is to provide the highest level of service reasonably possible for the longest period of time.

Thinlays are different from many other pavement preservation techniques because they improve the level of service and often extend service life longer than other preservation treatments. Although Thinlays will not fix significant structural problems, such as severe rutting or cracking, Thinlays will correct less severe problems, such as rutting of ½ inch or less, raveling, and minor cracking. Milling the existing pavement surface before placing a Thinlay further improves a Thinlay's ability to correct problems, because it improves existing pavement smoothness, often reduces the width of cracks, and will improve the bond between the Thinlay and the existing pavement.

A 2011 report from the Second Strategic Highway Research Program (SHRP 2) noted:

> "Thin [hot mix asphalt pavement] overlays can be used on all types of roadways in good to fair condition for functional improvements. Such overlays are particularly suitable for high-traffic-volume roadways in urban areas, where longer life and relatively low-noise surfaces are desired." (Peshkin et al., 2011)

The case studies included in this guide, as well as information included in the 2011 SHRP 2 report, show that when Thinlays are used correctly they can provide a benefit for 12 years or more, which provides notable life-cycle cost advantages over the life of the pavement. This can be seen in service life and cost information from the SHRP 2 report shown in Table 1.

The SHRP 2 report considered a "Thin HMA Overlay" to be a dense-graded asphalt pavement overlay of ⅞ inch to 1½ inches in thickness. "Ultra-Thin" was ½ to ¾ inch in thickness.

Table 1. SHRP 2 data on preservation treatment life and cost (Peshkin et al., 2011)

Treatment	Life, Years		Cost Per Square Yard		Square Yard Cost Per Year	
	Min	Max	Min	Max	Min	Max
Microsurfacing (single course)	3	6	$1.50	$3.00	$0.25	$1.00
Chip Seal (single course)	3	7	$1.50	$4.00	$0.21	$1.33
Thin HMA Overlay	5	12	$3.00	$6.00	$0.25	$1.20
Ultra-Thin HMA Overlay	4	8	$2.00	$3.00	$0.25	$0.75

Although the SHRP 2 information shows how service life and cost information may be analyzed, the actual service life and cost of any preservation treatment is significantly affected by many factors (e.g., traffic, market conditions, existing pavement conditions, contractor expertise, material quality, and environmental conditions), and such factors must be considered when evaluating service life and cost.

Protection From Water Damage

Thinlays will provide a water-resistant surface when designed and placed correctly. Permeability is important because moisture trapped in pavements can strip asphalt from the aggregate and expose the asphalt binder to oxygen, which will cause the binder to stiffen and become brittle. Over time, this weakens the pavement and makes it prone to cracking.

Research has shown that the permeability of asphalt pavement is greatly reduced for smaller NMAS mixes (9.5 mm and smaller). Figure 2 shows the results of permeability research performed at the National Center for Asphalt Technology (NCAT) on different NMAS mixes (Mallick et al., 2003). Clearly, the permeability of smaller NMAS mixes was much lower than that of the larger NMAS mixes at almost all levels of density (referred to as "in-place air voids" in Figure 2).

Because Thinlays utilize 9.5 mm and smaller NMAS mixes, Thinlays will be water-resistant and protect the underlying layers from moisture. A permeability of less than 200 × 10^{-5} cm/s, is typically considered an impermeable pavement surface.

Although impermeable, Thinlays are sufficiently breathable to allow water vapor to escape, and as such, will typically not cause stripping in the underlying pavement structure. Stripping is the separation of asphalt binder from aggregates through exposure to water or water vapor, and will significantly weaken the pavement structure. Chip seals and other seal coats have the potential to trap water and water vapor in the underlying pavement, which may cause or accelerate stripping (Wood, 2013).

Improved Structural Strength

Thinlay mixes are designed according to the Superpave mix design process using rigorous procedures and requiring the use of high-quality aggregates and asphalt binders. The compaction process forces the aggregates to interlock. The interlocking allows the mix to better resist shearing and cracking, which results in improved resistance to traffic loads.

A high-quality Thinlay will continue to resist damage from traffic loading for the duration of its life. Other preservation treatments have little or no ag-

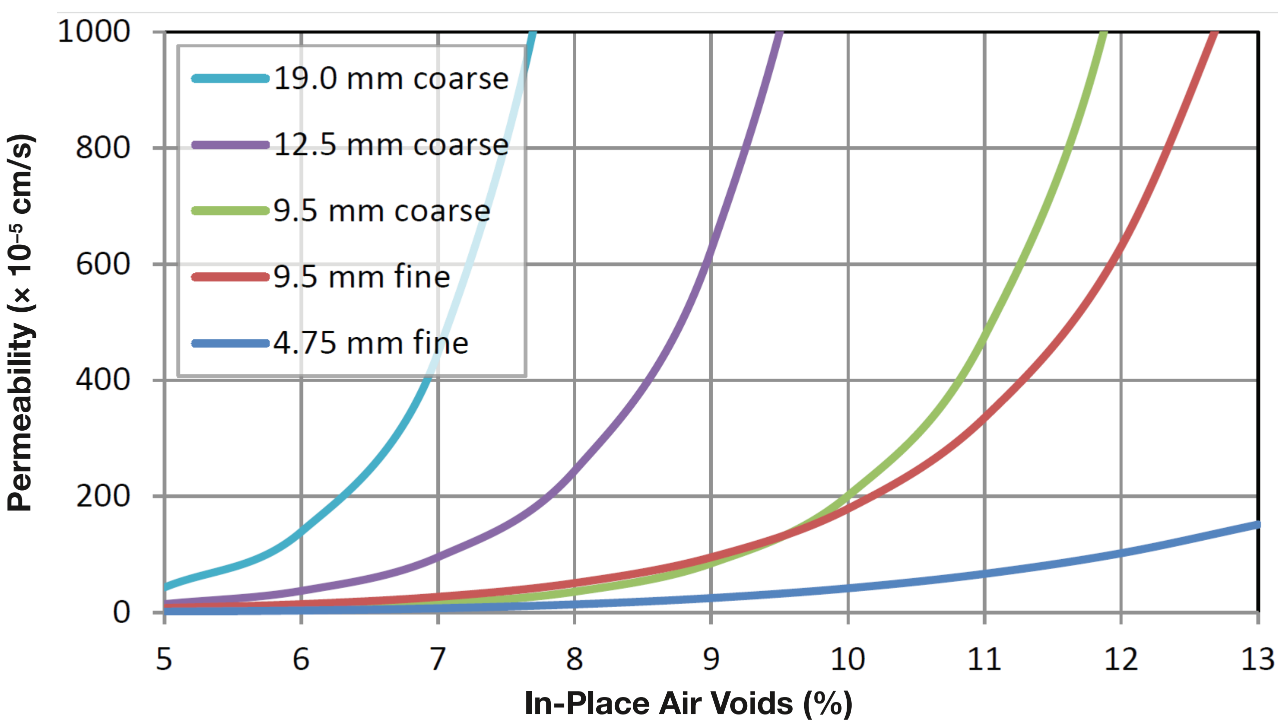


Figure 2. Effect of NMAS and air voids on permeability (after Mallick et al., 2003)

gregate interlocking and do not provide near the shear resistance of Thinlays.

Where a Thinlay adds thickness to an existing pavement section, the potential structural benefit is significant. Some pavements fail because repeated tensile strains at the bottom of the asphalt pavement layer cause cracking. If the tensile strains are reduced, the pavement will last longer. Tensile strains are reduced by increasing asphalt pavement thickness, which is done when Thinlays add thickness to a pavement (Huddleston, 2012).

If a Thinlay is placed on an existing pavement before the onset of fatigue cracking, it will delay and potentially prevent such cracking. Research has shown that many roads need only have an asphalt thickness of 5 to 6 inches to never develop fatigue cracking from the bottom up (Mahoney, 2001).

In some cases, a Thinlay will double the fatigue life of the pavement. The fatigue life of a pavement is a measure of how long a pavement will resist interconnected cracking throughout the entire pavement section. Using WESLEA linear elastic modeling software and the default transfer function to predict pavement fatigue life (Table 2), if a 3-inch-thick pavement is expected to last 20 years, adding 1 inch of asphalt will increase the life to 40 years. Adding another inch will double the fatigue life again.

Table 2. Asphalt thickness vs. fatigue life based on WESLEA linear elastic modeling

Thickness	Microstrain (με)	Reps to Failure
2	–652	30,234
3	–495	71,537
4	–383	160,693
5	–302	340,507
6	–242	682,133

Of course, the surface must be maintained when needed (e.g., if a Thinlay is placed, it will need to be replaced at the end of its service life). And while the extent of the benefit of a Thinlay on fatigue life will vary based on the condition of the existing pavement and traffic, in many cases the benefit will be significant.

Improved Ride Quality

Asphalt pavement overlays and inlays (where existing pavement is milled prior to application of new pavement layers) improve smoothness by leveling the surface and providing consistent texture. Because modern milling machines can mill at a specific elevation and provide a uniform surface, inlays often result in the greatest smoothness improvements.

Thinlays can be placed as an overlay or an inlay. Although Thinlays may not improve ride as much as thicker asphalt pavement sections, the improvement is significantly more than other common pavement preservation treatments. In general, seal coats and applications cannot even out the existing pavement surface because they do not vary in thickness, and will provide only a short-term improvement in texture.

A 2008 report by the University of Toledo, the Ohio Department of Transportation, and FHWA concluded that “the benefit of a thin overlay, in terms of improved ride condition, is very substantial for flexible pavements” (Chou et al., 2008). The report analyzed International Roughness Index (IRI) data (a measure of roughness in the wheel path) before and after application of thin overlays of 1½ to 2 inches in thickness.

As shown in Figure 3, placing a thin overlay on a pavement with an IRI of 140 would be expected to improve the IRI to 80, on average, and the ride quality would remain better than an IRI of 140 for 16 years.

Improved Drainage

Standing water caused by low spots like ruts is dangerous. As the depth of standing water increases, the potential for hydroplaning increases. Thinlay overlays will correct low spots, including ruts, if the depth is about ½ inch or less. Pre-leveling or inlaying a Thinlay after milling the existing surface will correct deeper low spots.

Other common preservation treatments are typically ineffective at removing low spots. Although microsurfacing can fill some low spots, it often requires more than one application, which increases cost and cure time during which traffic is prohibited from using the road.

Reduced Noise

The smooth surface created by Thinlays reduces noise, which is especially important when residences are close to roadways. Other pavement preservation techniques can increase the pavement surface's macro-texture, which can generating substantial noise.

In 2012, the Texas Department of Transportation (TxDOT) chip sealed 6.5 miles of RM 12 (an arterial connecting communities west of Austin) to restore skid resistance (Reyna & Silver, 2014). Users and nearby homeowners complained about the noise, and TxDOT also became concerned about aggregate loss. TxDOT tested the chip seal in six locations with the on-board sound intensity method using a vehicle equipped with microphones mounted close to the tire/pavement interface. The average relative loudness was 109.3 dB(A), which is louder than a gas-powered lawn mower at 3 feet.

TxDOT then placed a 1-inch thick overlay (referred to as a Thin Overlay Mixture by TxDOT) on RM 12 and retested the road in the same six locations. The average relative loudness was 96.3 dB(A) — which is a reduction in loudness of more than 50% (most people perceive one sound to be twice as loud as another at a difference of 10 dB(A)). TxDOT obtained similar reductions with thin overlays applied to older asphalt pavements.

NCAT analyzed the differences in noise generated by loaded trucks on different NMAS mixes at its test track at Auburn University (Hanson et al., 2004). NCAT found that coarser mixes generate more noise than finer mixes, which shows that Thinlays can be even quieter than typical asphalt pavements.

Elimination of Curing & Binder Runoff

Thinlays can be opened to traffic immediately after construction. Chip seals and microsurfacing typically use asphalt emulsions as a component of the treatment, which requires some amount of cure time before allowing traffic on the surface. The time required for curing depends on the type of emulsion, application rate, and climatic conditions, but is typically more than an hour and can be up to several hours.

Thinlays require a relatively low application rate of asphalt emulsion as a tack coat to bind the surface to the underlying pavement, and because the binder is blended with the aggregate in a Thinlay mix (just like typical asphalt pavement mixture), the asphalt binder will not drain from the mix. As a result, there

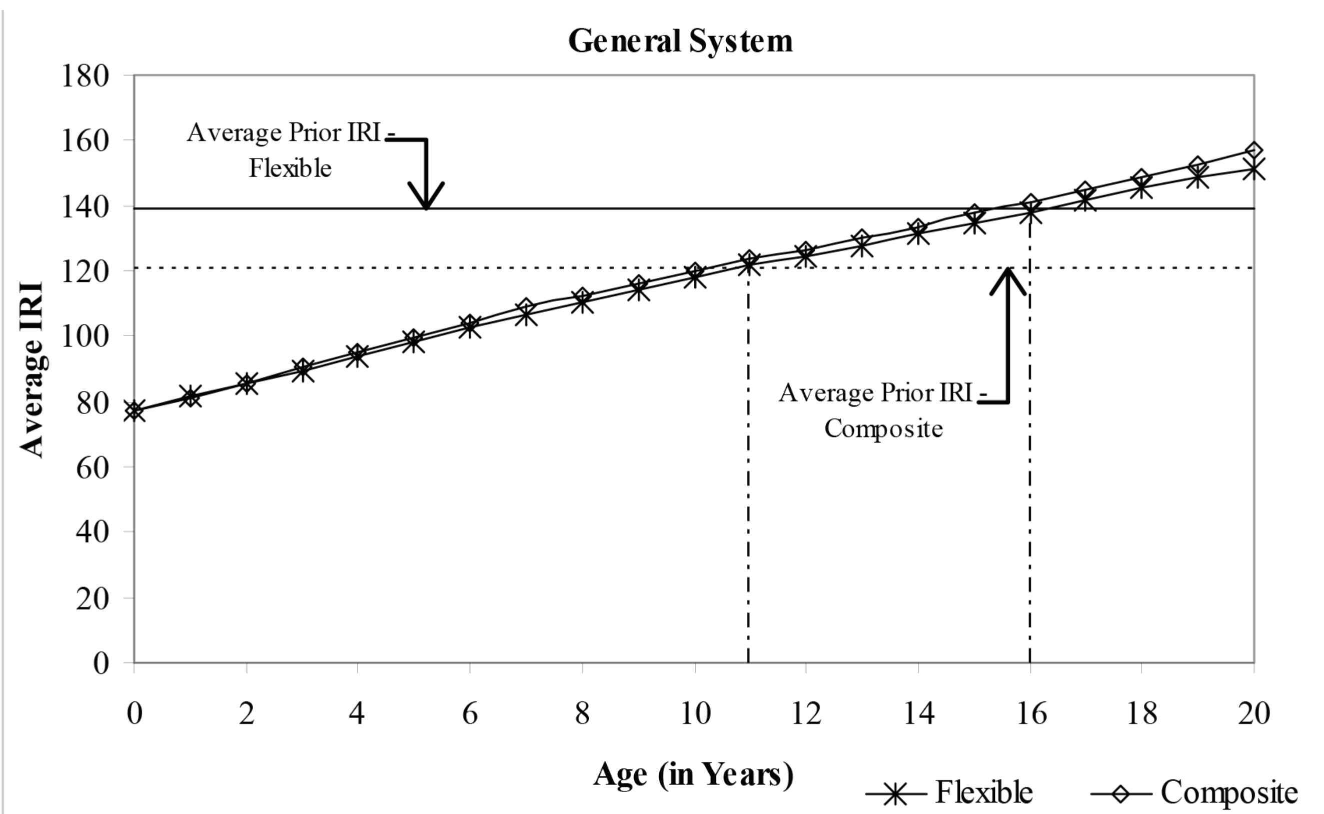


Figure 3. Effect of thin asphalt overlay on smoothness (Chou et al., 2008)

is a very low risk of asphalt emulsion or binder runoff from the construction area.

Sustainability

Thinlays can be designed to incorporate relatively high percentages of reclaimed and recycled materials, can be recycled themselves, and can reduce rolling resistance by improving megatexutre such that vehicle fuel use is reduced. Some Thinlays have successfully incorporated up to 35% reclaimed asphalt materials.

Thinlays can also be milled and recycled themselves, just as any other asphalt pavement surface. In addition to improving the sustainability attributes of Thinlays, incorporating reclaimed and recycled asphalt materials can also reduce costs. Most other pavement preservation treatments cannot or do not use reclaimed and recycled materials.

Reducing traffic fuel usage also contributes to sustainability. Fuel usage decreases with reduced rolling resistance, which is influenced by several roadway factors, primarily surface texture and smoothness — with smoothness having the biggest effect by far. Studies show that improvements in smoothness can improve fuel efficiency by 2–6% (Jackson et al., 2011).

Because Thinlays can provide a substantial improvement in smoothness, they will decrease fuel usage. No other common pavement preservation treatment decreases rolling resistance to the same extent as Thinlays, and treatments with rougher texture may even increase rolling resistance.

Controlled Production Process

Modern asphalt plants utilize highly specialized and controlled equipment to produce asphalt mixes, which are typically subject to frequent quality control testing in on-site laboratories. After Thinlay mixes are produced, they are trucked to the project site and placed with pavers that typically utilize electronic control equipment. Thinlays are then compacted by rollers designed to densify the asphalt materials and create a uniform surface.

Other preservation treatments are mixed in truck mixers or placed by spraying a layer of emulsified asphalt followed by applying a layer of aggregate. None of these processes are as controlled or repeatable as the process used for Thinlays. As a result, Thinlays have a more consistent surface texture and fewer instances of failure due to equipment malfunctions or construction practices.

Locally Available Experience

An important but less tangible Thinlay benefit is the availability of local contractors who can produce, place, and compact Thinlays. Asphalt pavement production and placement services are readily available across the country, and these same asphalt contractors have the equipment and expertise to place Thinlays. Contractors for other preservation treatments are not as readily available in all locations.

Preferred by Cyclists & Pedestrians

Cyclists and pedestrians prefer the smooth surface texture provided by Thinlays over other pavement preservation treatments that have a much rougher surface texture (Li et al., 2013).

Additionally, loose aggregates from chip seals and other pavement preservation techniques may collect on the side of the road where cyclists ride and pedestrians walk or run, increasing the risk of slipping. Loose aggregates may also be flung from vehicle tires and break windshields, damage vehicle paint, and hit cyclists and pedestrians.

Good construction and maintenance (e.g., sweeping) reduce the amount of loose aggregates, but does not completely prevent these problems. Thinlays eliminate these problems and provide a smooth texture that is enjoyable for all users.

An asphalt surfaced hiker–biker path.

A Thinlay is placed on U.S. Highway 49 near Belzoni, Mississippi.

3 Common Pavement Preservation Techniques

The primary purpose of pavement preservation is to preserve a road that is in good condition to help delay or reduce the cost of reconstruction. Simply allowing roads to deteriorate to the point where major rehabilitation or reconstruction is needed costs significantly more than preserving roads that are in good condition (Peshkin et al., 2011).

Ideally, preservation treatments seal the surface and provide a smooth, quiet, safe ride for traffic. The surface should also be durable to minimize future closures and reduce life cycle cost.

The most common treatments are thin overlays, chip seals, and microsurfacing.

Although placing a thin asphalt pavement layer on existing pavement is not a new concept, Thinlays are different from traditional thin overlays because they utilize a finer aggregate structure and often incorporate more durable asphalt binders. The finer aggregates allow for the aggregate structure to lock together better when placed thin, and the more durable binders provide added crack resistance.

The typical NMAS in a Thinlay is 6.4 or 9.5 mm (often referred to as ¼- or ⅜-inch mixes, respectfully), with the finest Thinlays having a NMAS of 4.75 mm. A 4.75 mm NMAS Thinlay may be placed as thin as ⅝ inch, a 6.4 mm NMAS Thinlay may be placed as thin as ¾ inch, and a 9.5 mm NMAS Thinlay may be placed as thin as 1 inch.

Chip seals (often referred to as bituminous surface treatments) have been used for many years to provide a waterproof surface on low volume roads. Chip seals can also be used to treat pavement surface raveling and oxidation. Chip seal placement involves spraying an asphalt emulsion layer and immediately covering it with aggregate chips. The chips are then rolled to seat them in the emulsion and to help with bonding.

Chip seals are sometimes placed in multiple layers. One layer, consisting of asphalt emulsion and chips, is followed by another layer. Although the cost of a chip seal will vary considerably depending on whether it is a single or double chip seal, chip seals often have the lowest initial cost among the common preservation treatments. The benefits of chip seals are not as significant, however, and often do not last as long as the benefits of the other common pavement preservation treatments. Other drawbacks, such as loose chips, variable life, and relatively high noise, also detract from the appeal of relatively low initial cost.

Microsurfacing was developed in the 1960s and 1970s in Germany to provide a mixture that could be used to fill ruts and prevent water ponding and hydroplaning (ISSA, n.d.). Microsurfacing was adopted in the United States in the early 1980s. Initially it was used to fill ruts, but its use has expanded to general pavement preservation. Microsurfacing incorporates polymers and other additives in an asphalt emulsion. Although the additives improve performance, they increase cost and cure time. Microsurfacing costs also vary considerably depending on whether the treatment is applied in one layer or multiple layers.

Compaction of a Thinlay mixture

4 Pavement Management Systems

Managers use pavement management systems to track road conditions and help select preservation treatments that will minimize the life-cycle cost for roads. A key initial step is determining the existing road condition, and most agencies evaluate and rate the condition of the roads in their jurisdiction on a regular basis. The rating given to a road is often expressed as the road's Pavement Condition Rating (PCR), which is designated as a number.

Several pavement distress considerations are used in determining the PCR. Each distress is identified by type, extent, and severity, which determines the number of points to deduct when establishing an overall condition score for the road.

Common distresses include: roughness/ride, rutting, fatigue cracking, thermal cracking, surface raveling, delamination, friction loss, and poor surface texture. In 2014, FHWA published the *Distress Identification Manual for the Long-Term Pavement Performance Program* (Miller & Bellinger, 2014), which is an excellent guide for rating pavement conditions.

Over time, managers gather enough data to create pavement performance curves, which allow them to better monitor and predict distresses. The *y*-axis of a pavement performance curve is the PCR, and the *x*-axis is normally time or traffic. Understanding the relationship between time or traffic and PCR allows an engineer to determine when a preservation treatment should be applied, which helps engineers predict funding needs several years in advance.

Pavement preservation treatments are most cost-effective if applied before the PCR drops too low. Treatment will increase the PCR to some extent, after which the PCR will again decrease as the pavement develops distresses that increase in severity over time. Figure 4 is an example of a pavement performance curve showing how a pavement preservation treatment can extend a pavement's performance life.

All roadway segments in a classification group are assigned to categories ranging from good to poor based on their PCR. Pavements that are good but expected to drop to fair condition in the near future

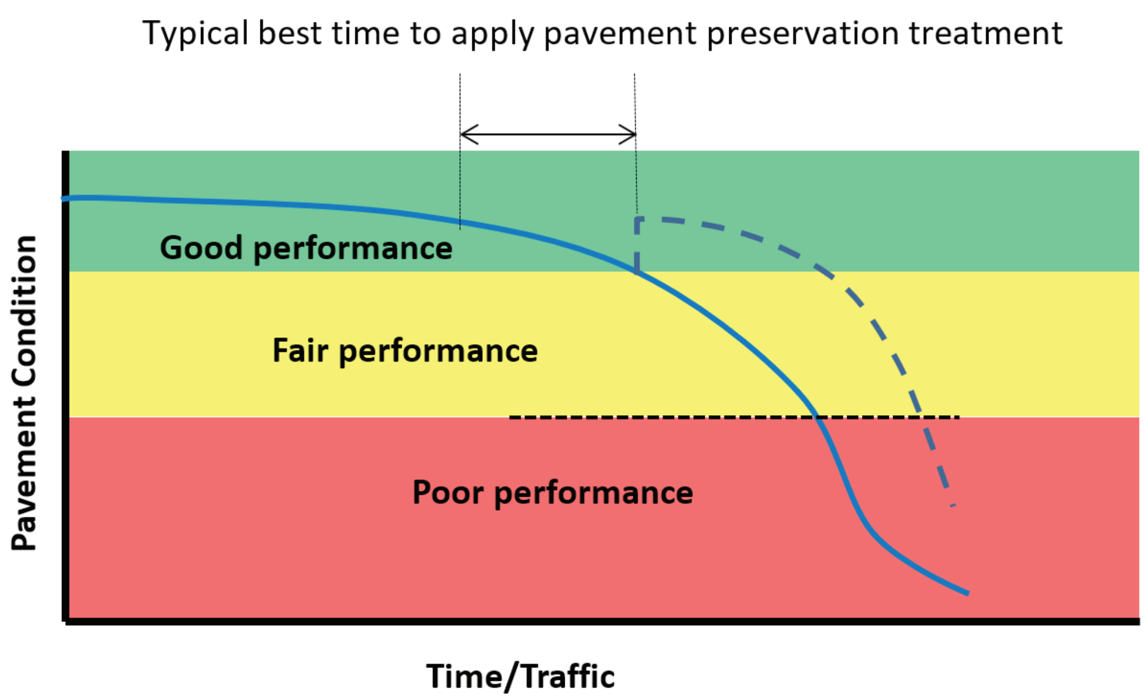


Figure 4. Pavement management performance curve

are usually considered cost-effective candidates for preservation. Roadway segments that are expected to remain good for several more years will not gain the greatest benefit from a preservation treatment. Figure 5 shows how preservation treatments affect pavement condition curves.

Roadways at the end of the good performance section of the curve generally have good ride, low severity rutting, low severity non-load related cracking, and no significant fatigue cracking. Regardless of the timing or type of preservation treatment, the pavement should be examined to determine the type and severity of distresses and whether isolated repairs are needed prior to placing a preservation treatment.

Thinlays fit within pavement management systems just like other preservation treatments. Thinlays will have a bigger initial increase in PCR, however, due to the improvement in ride quality. In many applications, Thinlays will also slow the reduction of PCR over time due to the extended period that its benefits will remain evident (Chou et al., 2008).

In some cases, Thinlays will eliminate entire classes of distresses. For example, when Thinlays increase the thickness of existing pavement sections that do not have significant fatigue damage, the tensile strains at the bottom of the pavement section will be reduced. If the added thickness reduces strains such that fatigue damage does not accumulate at the bottom of the pavement section, the pavement will not develop bottom-up cracking. Distresses will be confined to starting at the pavement surface.

It is desirable for distresses to start at the surface for the obvious reason that those distresses are visible to the naked eye, allowing for repair before they become too severe. Such pavements are called Perpetual Pavements, and will typically have less of a downward slope on pavement condition curves as compared to pavements that develop both bottom-up and top-down distresses.

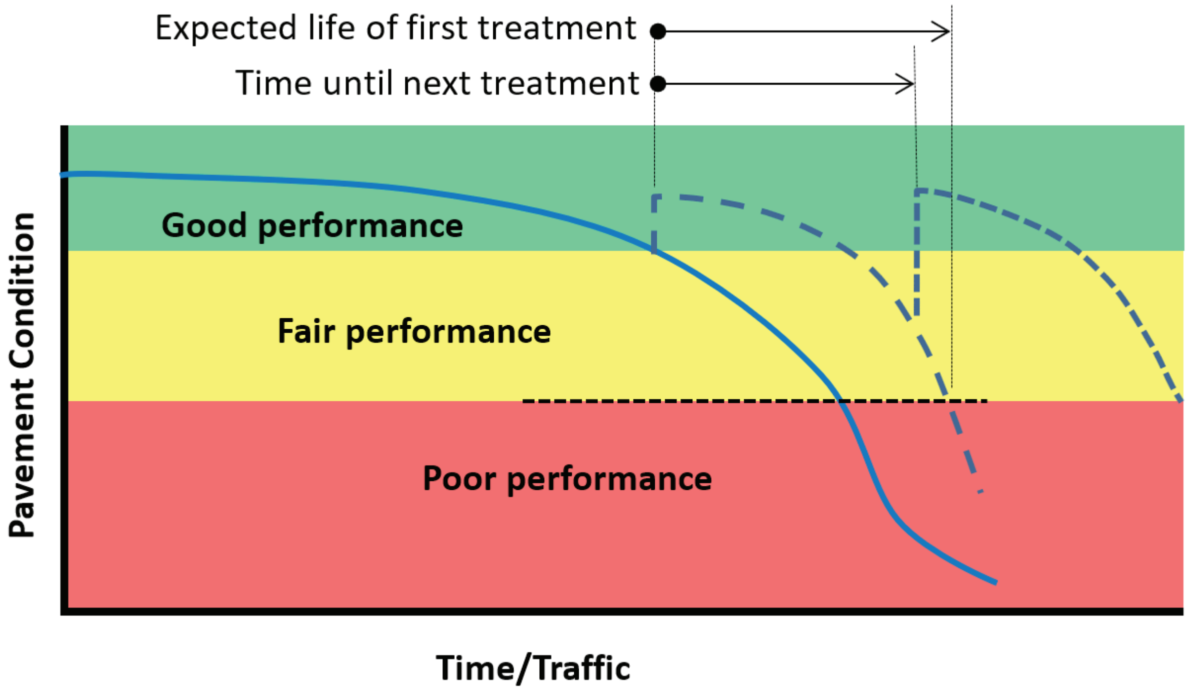


Figure 5. Pavement performance curve showing the preferred time for treatment

5 When to Use Thinlays

Common pavement distresses are listed in Table 3 below with general recommendations on whether and when Thinlays will be most effective. Additional details and photographs follow.

Table 3. Pavement distresses and when to use a Thinlay for pavement preservation

Existing Distress	Use Thinlays	Do Not Use Thinlays
Rutting	Where rutting is ½ inch or less	Where rutting is greater than ½ inch (unless milling or pre-leveling before placing Thinlay)
Age Hardening Cracking (Block Cracking)	Where crack widths do not exceed ¼ inch	Where block cracking has progressed to alligator cracking or cracks wider than ¼ inch
Loading Cracking (Fatigue Cracking)	After patching isolated areas of full depth fatigue cracking, in areas of top-down fatigue cracking if cracking is low severity, or where milling is used to eliminate or reduce top-down cracking	Where there is medium- or high-severity full-depth fatigue cracking (close interconnected cracking covering more than 20% of surface and/or where cracks are wider than ¼ inch)
Cold Temperature Cracking (Thermal Cracking)	Where full-depth repairs are made in areas of thermal cracking (if full-depth repairs are not made, Thinlays will preserve pavement between thermal cracks and may be effective when thermal cracks are far apart)	Without first making full-depth repairs in areas of thermal cracking
Cracks in Underlying Materials (Reflective Cracking in Existing Pavement)	Where full-depth repairs are made in areas of reflective cracking (if full-depth repairs are not made, Thinlays will preserve pavement between reflective cracks and may be effective when reflective cracks are far apart)	Without first making full depth repairs are made in areas of reflective cracking
Cracking Caused by Improper Mixing or Construction	Except where cracking has progressed to alligator cracking or full-depth cracks in or adjacent to wheel paths	Where cracking has progressed to alligator cracking or full-depth cracks in or adjacent to wheel paths
Roughness	In almost every case	Where there is extremely high severity roughness
Friction Loss	All cases of friction loss or textural problems	N/A
Raveling	In almost every case	Where raveling caused by stripping throughout the pavement structure may indicate the existing pavement lacks sufficient structural strength and must be reconstructed
Delamination	After milling or patching areas of delamination	Without first milling or patching areas of delamination
Bleeding	In all cases, provided existing pavement is sufficiently stable for construction loads and milling is performed in areas of high-severity bleeding	Without first milling areas of high-severity bleeding (milling will ensure an adequate surface for bonding the Thinlay to the existing surface)
Permeability	In all areas of excessive porosity	Where permeability has caused stripping throughout the pavement structure

Rutting

Although it depends on the cause of rutting, Thinlays may typically be placed as overlays where rutting is ½ inch or less (Figure 6). If the rutting is deep (more than ½ inch), as shown in Figure 7, milling and/or pre-leveling will be required before placing a Thinlay.

Rutting can be caused by factors including densification under repeated traffic, plastic flow of asphalt mix, inadequate support from underlying materials, or wear from studded tires. If an asphalt pavement is several years old and the rutting is ½ inch or less, rutting is likely the result of densification of pavement materials or wear from studded tires and is not related to unstable materials in the pavement structure. Thinlay overlays or inlays will correct such rutting and will be an effective preservation treatment.

Figure 6. Rut depth less than ½ inch

Figure 7. Rut depths exceeding 1 inch

If an asphalt pavement is several years old and rutting exceeds ½ inch, the pavement should be milled to remove or make the ruts shallower than ½ inch before placing a Thinlay. If the rutting was not caused by inadequate support from the underlying materials, milling followed by a Thinlay will be a very effective preservation treatment.

A general indication that rutting was caused by inadequate support in the underlying materials is if the rutting has continued to worsen beyond two years after paving. If there is uncertainty whether there are adequate underlying support materials, core samples from the asphalt pavement and subgrade materials should be analyzed by an experienced asphalt pavement technician.

Cracking

Thinlays are best utilized to preserve asphalt pavements that are in good condition. If Thinlays are applied before cracks widen too much, or before too many cracks have advanced through the entire pavement thickness, they will often be an effective pavement preservation treatment The presence of extensive cracking, or cracks wider than ¼ inch, often indicates the need for repair in addition to preservation.

Determining whether a Thinlay is appropriate when the existing asphalt pavement is cracked requires analyzing the cause and extent of the cracking. Cracks in asphalt pavement may be caused by age, loading, cold temperatures, cracks in underlying materials, or improper mixing or construction. This section provides guidance on how to analyze the cause of existing cracking and how to evaluate the effectiveness of Thinlays to preserve cracked asphalt pavements. Each of the primary crack causes are addressed in the sections below and are followed by Thinlay crack sealing considerations.

Age Hardening

As pavements age, they become stiffer from oxidation and other factors that cause the asphalt binder to harden, making the pavement more susceptible to cracking. Age hardening along with one or more other factors may combine to cause a crack, although cracking can be caused by age hardening alone.

Age cracking is often large, interconnected rectangular blocks demarcated by cracks, and is referred to as block cracking (Figure 8). The rectangular pieces vary significantly in size from about 1 to 100 square feet. The asphalt binder in such pavements lost the flexibility to withstand expansion and contraction forces caused by temperature fluctuations, and the cracks form in a relatively consistent pattern. Similar cracking can occur in newer pavements if the asphalt binder is too stiff.

Thinlays are an effective pavement preservation treatment for block cracking. Block cracks do not typically vary significantly in width with temperature changes, and Thinlays will seal the surface and delay further age hardening.

Loading

Traffic loading causes stresses and strains in pavements. Cracking due to loading happens when the structural strength of a pavement is exceeded by its traffic load, and is often referred to as fatigue cracking. Repeated or very high strains may lead to fatigue cracking.

Fatigue cracking is a common distress in thinner pavements, where cracking starts at the pavement section bottom where tensile strains are the greatest. This is referred to as bottom-up cracking. As asphalt pavement thickness is increased, strains decrease for the same load. In thicker pavements, fatigue cracking starts at the pavement surface (top-down cracking) and does not develop at the bottom (Mahoney, 2001).

Whether bottom-up or top-down, fatigue cracking typically begins as longitudinal (parallel to the travel direction) cracking either in or adjacent to the wheel paths (Figure 9). Thinlays are an effective pavement preservation treatment — as an overlay or an inlay — when placed before such cracking progresses to interconnected or alligator cracking, or when cracks are less than ¼ inch wide. Wide, interconnected, or alligator cracking indicates structural failure, and failed areas will degrade quickly whether or not a preservation treatment is applied. If failed areas are isolated, those areas should be repaired before applying any preservation treatment. If failed areas are widespread, the pavement will require more extensive rehabilitation.

Thinlays placed before fatigue cracking progresses into structural failure will seal the surface and extend the remaining pavement fatigue life. Milling top-down fatigue cracking to the bottom of the cracks before placing a Thinlay is an especially effective pavement

Figure 8. Heavy block cracking with sealed cracks

preservation technique because it eliminates the existing distress and provides a uniform surface that will bond well to a Thinlay.

It is common to see localized areas of alligator cracking while other areas may have little or no cracking. In such cases, the alligator cracked areas should be repaired before placing a Thinlay. The Thinlay will provide a uniform smooth surface over the entire pavement and provide additional structural capacity when overall pavement thickness is increased by the Thinlay, which will also reduce the likelihood of future fatigue cracking.

There are some cases where interconnected bottom-up or alligator cracking is extensive. In such cases, no pavement preservation treatment will be effective, and it is typically better to reconstruct the entire pavement by removing failed areas, placing adequate base material, and repaving with adequate thickness. Figure 10 shows fatigue cracking that has progressed too far for a Thinlay to preserve the pavement without first repairing the areas of alligator cracking.

Figure 9. Longitudinal cracking

Figure 10. Extensive alligator cracking

Cold Temperature

Cracking caused by cold temperatures is called thermal cracking. It occurs when the pavement temperature drops below the asphalt binder's tolerable low temperature. For example, a PG 64–22 asphalt binder must meet certain performance requirements (including resistance to thermal cracking) at temperatures between –22°C and 64°C. Temperatures below the low temperature grade of the asphalt binder (e.g., temperatures colder than –22°C in this example) may cause thermal cracking.

Although pavements placed before adoption of the Superpave PG (performance grade) system were not graded using this methodology, the concept is the same — the asphalt binder has a low temperature tolerance limit and if the pavement temperature drops below that limit, the pavement may crack.

Thermal cracks (Figure 11) are typically transverse (perpendicular to the travel direction), and full-depth (the crack exists throughout the entire pavement thickness). The more distance between thermal cracks, the greater the crack expansion and contraction that will occur with temperature changes (e.g., there would be more expansion and contraction between cracks that are 100 feet apart than between cracks that are 50 feet apart). Over time, repeated expansion and contraction will damage adjacent pavement (Figure 12). Many times, one side of the transverse crack will be slightly higher than the opposite side, with the higher side being subject to additional damage such as impacts from snowplows and similar equipment (Figure 13).

If a new asphalt pavement is placed over thermal cracking, the preexisting cracks will cause cracking in the new pavement. Cracking in an asphalt pavement overlay or inlay that is directly above an existing crack in the underlying pavement is called reflective cracking. In general, cracks in an existing pavement will reflect through new asphalt pavement at a rate of about 1 inch per year.

Because Thinlays are so thin, thermal cracks will reflect through to the surface quickly (for a 1-inch Thinlay, a thermal crack in the underlying pavement may appear at the Thinlay's surface in about one year). When the transverse cracks reflect through a Thinlay, they should be promptly sealed with normal crack seal-

Figure 11. Thermal cracking

Figure 12. Transverse crack with adjacent deterioration

Figure 13. Transverse crack with adjacent snowplow damage

ing materials and methods.

While Thinlays will not fix thermal cracking, they can improve the ride, especially in the areas between the transverse cracks. If transverse cracking is localized or widely spaced, Thinlays will be more effective than most other preservation treatments.

Milling before placing a Thinlay on a thermally cracked pavement often will not significantly delay reflective cracking because thermal cracks are full-depth, but milling will improve the existing pavement directly adjacent to and between thermal cracks.

Cracks in Underlying Materials

The existing pavement surface may be cracked because older asphalt pavement under the existing pavement surface is cracked (i.e., the existing cracks may be reflective cracks) (Figure 14). As with thermal cracking, Thinlays will not fix reflective cracking. If such cracks are more than ¼-inch in width and cover 20% or more of the pavement surface, Thinlays will not be an effective preservation treatment because they are likely to develop reflective cracking relatively quickly.

Figure 14. Reflective cracking

Figure 15. Overbanded crack sealing.

If reflective cracking is localized or widely spaced, however, Thinlays will be more effective than most other pavement preservation treatments. Just as with thermal cracking, milling before placing a Thinlay on a reflective cracked pavement often will not significantly delay reflective cracking through the Thinlay, but milling will improve the existing pavement directly adjacent to and between reflective cracks. When the cracks reflect through the Thinlay, they should be promptly sealed with normal crack sealing materials and methods.

Crack Sealing

Where a Thinlay will be an effective pavement preservation treatment, sealing cracks before placing a Thinlay is not required. Special care must be taken, however, if existing cracks have been sealed 12 to 18 months prior to Thinlay placement, or where crack-sealing material has been overbanded and the sealing material sits slightly higher than the crack edges and road surface (Figure 15).

Crack seal material that has not fully cured will expand when hot asphalt pavement is placed on it, and cause bumps in the Thinlay surface. Even if the material has cured, bumps in the existing pavement from overbanded crack seal material may cause bumps in the Thinlay surface because the Thinlay may not have sufficient thickness to even out the surface. Such bumps reduce ride quality and may cause Thinlay to lose adherence to the pavement below (debonding). Fine or micro milling may be used to remove excess crack seal material. Allowing crack seal material to cure before placing a Thinlay will also help prevent bumps that would otherwise be caused by expansion of the crack seal material during Thinlay placement. Although the cure time will depend on the material used, allow at least 12 months before placing a Thinlay.

Crack treatment methods are available for existing cracks of about ¼ inch wide or wider. Paving fabrics and underseals, for example, have been used successfully to delay reflective cracking in some areas of the country. Supplier instructions and local best practices must be followed when such methods are used with Thinlays. Because Thinlays are thinner than traditional overlays and inlays, Thinlays will cool faster and may not maintain enough heat to properly activate crack treatments that require heat. Thinlays will also be more susceptible to slippage failures than traditional overlays and inlays, as well as to showing bumps and depressions on or in the existing pavement surface. If there is limited experience with a crack treatment method in an area, evaluate test sections before incorporating the method into a pavement preservation program.

If cracks in the existing pavement reflect through a Thinlay, the cracks should be promptly sealed using normal crack sealing methods.

Improper Mixing or Construction

Cracking due to improper mixing or construction is often caused by practices that inhibit compaction, which results in insufficient density. For example, failing to compact asphalt pavement before it cools below its minimum compaction temperature or having insufficient asphalt binder in the mixture will reduce density. Asphalt pavements that lack sufficient density are more permeable than dense pavements and are more prone to cracking.

Common signs of improper mixing or construction include non-uniform surface texture (pockets of larger and smaller aggregates rather than a consistent blend of aggregates); joints that don't properly overlap, and as a result hold water longer than the rest of the pavement surface; and cracks at joint locations. Cracking due to improper mixing or construction can be longitudinal or transverse.

Thinlays are effective pavement preservation treatments where improper mixing or construction caused cracking, provided the cracking is not part of a structural failure. If the cracking is top-down and individual cracks are ¼ inch or less in width, Thinlays can be placed as an overlay. As explained above, milling is especially beneficial for top-down cracks because it can eliminate the existing distress and provide a uniform surface that will bond well to a Thinlay. If the cracking has progressed to full-depth cracking, Thinlays will not be effective and the cracked area(s) will need full-depth repair.

Roughness

Pavement roughness is often described as irregularities in a pavement surface that adversely affect vehicle ride quality (i.e., bumpiness). As pavements age, their roughness often increases. Increased roughness can be caused by raveling, cracking, weathering, movement of the pavement mix under traffic, and other environmental and loading issues. If the roughness is not excessive, it can be corrected with a Thinlay overlay. Where roughness is caused by distresses greater than ½ inch in depth, milling is needed to level the surface prior to Thinlay placement.

A Thinlay is the only pavement preservation treatment that will substantially improve roughness, but the longevity of the improved ride depends on what caused the roughness. For example, a Thinlay will provide only temporary benefit for a pavement whose roughness is caused by a large number of deteriorated transverse cracks or overall structural failure.

Transverse cracks and other structural failures will reflect through an overlay relatively quickly and cause roughness to increase. However, if the roughness is caused by raveling or less severe cracking (e.g., cracking caused by improper joint construction or other construction-related issues), a Thinlay will greatly improve the roughness for an extended period — up to 16 years or more (Chou et al., 2008).

Figure 16. Slight raveling

Figure 17. Slight raveling in and adjacent to longitudinal crack

Figure 18. Severe raveling

Friction Loss

There are some cases where the pavement surface loses friction. Friction loss can be caused by polishing of surface aggregate (a loss of texture on the aggregates themselves), asphalt mix bleeding (excess asphalt binder on the surface of the asphalt pavement), and low spots that accumulate water (e.g., ruts). Polishing progresses as traffic wears the surface aggregates, and is present to some extent in all pavements. Bleeding and rutting, however, are usually indicators of problems with the existing asphalt pavement mix. In areas with adequate drainage, Thinlays are very effective at improving surface friction.

Pavement texture (characterized by deviations in the surface) is the dominant pavement friction factor, and is separated into two categories: microtexture and macrotexture. Microtexture refers to deviations in the surfaces of the aggregates themselves, and macrotexture refers to the peaks and valleys between closely spaced aggregates. Microtexture is critically important at speeds under about 45 miles per hour in both wet and dry conditions. Thinlays utilizing crushed aggregates that satisfy local hardness requirements will typically provide adequate microtexture.

Macrotexture becomes more important as speed increases, especially in wet conditions. When roads are wet, the water on the surface fills the deviations between aggregates at the surface and, if the water does not drain off of the surface adequately, it will prevent the tire from contacting the aggregates and will cause hydroplaning at higher speeds. Where Thinlays eliminate rutting or puddling and help level the travel surface, they will also improve macrotexture and reduce the risk of hydroplaning.

If delaminated areas are isolated and are removed and patched, a Thinlay will be an effective preservation treatment over the entire pavement surface. For widespread delamination, milling of the delaminated layer is required. In such areas, a thicker asphalt pavement inlay may be required to ensure adequate structure.

Raveling

Raveling is the loss of aggregates from the asphalt pavement surface. Raveling typically occurs in low density areas. Aggregate segregation (pockets of larger and smaller aggregates rather than uniform distribution) and poor joint compaction can lead to raveling. Thinlays are an effective pavement preservation treatment in areas exhibiting low- to medium-severity raveling (Figures 16 and 17).

Thinlays should not be used, however, if raveling is caused by stripping (asphalt binder washing off the aggregate) within the pavement section. If stripping within the pavement section — meaning it occurs beyond the aggregates at the surface — has progressed to raveling (Figure 18), the existing pavement will deteriorate quickly regardless of the preservation treatment applied. In such situations, the existing pavement needs to be removed and replaced.

Delamination

Delamination occurs when there is a bond loss between two layers of asphalt pavement. Slippage failures are often identified by U-shaped cracking (Figures 19 and 20). No pavement preservation treatment will be effective in such areas.

Figure 19. Asphalt pavement slippage

Figure 20. Slippage close up

Bleeding

Bleeding is where asphalt binder migrates to the pavement surface and creates a shiny black film. Bleeding will significantly lower friction and is a sign that the pavement structure may be unstable. Bleeding is typically caused by too much asphalt binder in the asphalt pavement mix or too much compaction (insufficient air voids) (Figure 21).

Bleeding often happens soon after construction when traffic has driven on the pavement. If bleeding is excessive or accompanied by rutting in pavements less than two years old, a Thinlay overlay will not be effective. In such cases, the pavement section should be investigated to determine whether the pavement has sufficient stability.

If the bleeding and instability is confined to the pavement surface, a Thinlay may be effective, but milling will be required prior to placement.

If the bleeding is not excessive and not coupled with rutting, a Thinlay overlay or inlay will provide a new surface and improved friction. Although a tack coat should still be applied in these cases, less tack than normal should be used because asphalt binder that has bled to the surface will help with bonding and normal tack quantities coupled with the asphalt binder at the surface could cause a slip plane.

Figure 21. Bleeding

Permeability

Unless an asphalt pavement is intended to be permeable (e.g., an open-graded friction course or a full-depth porous asphalt pavement), water should not penetrate the surface. Although permeability alone is not a pavement distress, it can lead to pavement distresses, such as raveling and cracking (Figure 22).

Thinlays are exceptionally effective where permeability exists but has not yet led to a distress. Because Thinlays are waterproof, they will seal the surface and preserve the pavement structure if it has not already developed distresses.

Figure 22. Water penetration in a pavement

6 Material & Mix Design for Thinlays

Thinlays utilize the same materials and mix design process as conventional asphalt pavements with important exceptions — one being that, because Thinlays are thinner than conventional asphalt pavements, Thinlays must have smaller nominal maximum aggregate sizes (NMAS) and finer gradations. Also, because the aggregate is finer, there are more individual rocks and more rock surface area to cover, so the asphalt binder content is typically higher than conventional asphalt pavement mixes. Certain aspects of the mix design process can also be used to enhance Thinlay crack resistance.

Some states have developed material and mix design specifications for Thinlays based on research, experience, specific needs, and local practices. In those states, the local specifications and experiences should be investigated before creating new specifications based on this or other guidance. No specifications or guidance should be used without considering their intended use. For example, specifications for Thinlay material and mix design intended to be used on high volume roads or highways will be inappropriate for rural county roads or residential areas, and vice versa. Material and mix design principles generally applicable to Thinlays are set forth below.

Aggregate

Contractors routinely select aggregate sources to meet gradation and quality requirements for conventional asphalt pavement mixes. In most cases the same aggregate sources can be used for Thinlays. In some cases, however, different aggregate sources may be required to ensure that aggregates can be produced and consistently blended to meet the Thinlay finer gradation requirements.

The same aggregate quality requirements for conventional asphalt pavement mixes also apply to Thinlays. Most areas specify that aggregates must have the properties specified in the Superpave system, which requires aggregates to possess certain properties relative to coarse and fine aggregate angularity, flat and elongated particles, and clay content. The Superpave system also addresses toughness, soundness, and deleterious materials, but does not specify critical values as they are source-specific.

Coarse and fine aggregate angularity properties are important because they create internal friction in asphalt pavement mixes, which correlates to shear strength (rutting resistance). Flat and elongated particle content is typically limited by specification because these particles break more easily than aggregates that are more cubical, and can contribute to aggregate breakage susceptibility in mixes. Clay content is also typically limited by specification in order to enhance the bond between asphalt binder and the aggregate. (Asphalt Institute, 2001). The aggregate properties specified in Superpave are shown in Table 4.

Requirements for toughness, soundness, and deleterious materials are typically specified by the state department of transportation, and are tested at most asphalt pavement aggregate sources (Asphalt Institute, 2001). Toughness is measured by the L.A.

Table 4. Superpave aggregate property requirements (Asphalt Institute, 2001)

Design ESALs (million)	Coarse Agg. Angularity		Fine Agg. Angularity		Sand Equiv. Value	Flat & Elongated	
	<100 mm from surface		<100 mm from surface		% min	% max	
NMAS	9.5	4.75	9.5	4.75	9.5/4.75	9.5	4.75
<0.3	55/—	—	—	40	40	—	—
0.3 to <3	75/—	—	40	45	40	10	—
3 to <10	85/80	—	45	45	45	10	—
10 to <30	95/90	—	45	45	45	10	—
>30	100/100	—	45	45	50	10	—

abrasion test, which tests how well coarse aggregates resist abrasion and degradation. Soundness is measured by the sodium sulfate or magnesium sulfate soundness test, which measures how well aggregates will resist weathering. Deleterious materials are measured by the clay lumps and friable particles test, which tests for the percentage of clay, shale, wood, mica, and coal in the blended aggregate.

RAP and RAS

Most asphalt mixes, including those for Thinlays, contain some reclaimed asphalt pavement (RAP) or recycled asphalt shingles (RAS). Although RAP and RAS are not required, they are often desirable because they increase the mix's sustainable attributes and can reduce cost.

The percentage of RAP or binder replacement from RAP allowed in a Thinlay mix should not exceed the typical maximum for conventional asphalt pavements in the area unless there is local experience or sufficient research showing that Thinlays with higher RAP percentages will perform acceptably.

For Thinlays, the RAP should be fractionated or screened to prevent oversized RAP aggregates from getting into the Thinlay mix. When screened, finer RAP stockpiles will have a higher asphalt binder content because their coated aggregate surface area will be greater than the coated surface area of coarser material. The higher asphalt binder content should be accounted for in the mix design process.

Similar to RAP, the RAS content used in Thinlay mixes will affect the asphalt binder properties of the mix. The percentage of RAS or binder replacement from RAS allowed in a Thinlay mix should not exceed the typical maximums for conventional asphalt pavements in the area unless there is local experience or research on local asphalt pavement mixes with higher RAS percentages. The RAS particle size after grinding must be sufficiently small so the RAS blends with the other mix components, and, as with RAP, the RAS binder content should be accounted for in the mix design process.

For detailed information on the use of RAP and RAS in mix designs, see *Best Practices for RAP and RAS Management* (QIP-129) from the National Asphalt Pavement Association (West, 2016).

Asphalt Binder

Although a complete asphalt binder explanation is beyond the scope of this guide, fundamental principles that are critical to asphalt binder selection for Thinlays are described below.

Asphalt binders are performance-graded based on the temperature range within which they will perform acceptably. For example, a PG 64–22 asphalt binder must meet certain performance requirements up to 64°C, and down to –22°C. The greater the first number, the more resistant the binder will be to high temperature distresses, such as rutting and shoving. The lower the second number, the more resistant the binder will be to low-temperature cracking. The grading system uses 6-degree increments for both numbers. For example, the next higher and lower grade asphalt binder from a PG 64–22 is a PG 70–28 (70°C is the next higher high temperature grade, and –28°C is the next lower low temperature grade).

The temperature grades refer to pavement temperature, which is different from air temperature. The first number is the pavement temperature converted from a seven-day

Figure 23. A Thinlay incorporating 40% RAP is used to restore ride quality to a rough PCC pavement.

average high temperature, and the second number is based on a single-day low temperature.

In the asphalt binder selection process, after the high and low temperatures for an area are determined based on historical climate data and a selected statistical reliability, those temperatures are converted to pavement temperatures.

The Federal Highway Administration publishes free LTPPBind software to help engineers select the most appropriate performance-grade asphalt binder. The software is available for download at: *https://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/pavements/ltpp/install.cfm*. The software contains climate data from across the country and will convert air to pavement temperature.

In addition to selecting the appropriate temperature range, other variables must also be considered, including traffic volume and speed, RAP and/or RAS content, and availability of different asphalt binder grades.

Traffic volume and speed influence the high temperature grade such that the high temperature grade should be higher for high traffic volumes and slow speeds (where traffic congestion results in loads sitting on pavement for longer periods of time). RAP and RAS will stiffen the mix, which requires designers to account for the stiffening in selecting the asphalt binder grade.

The extent of stiffening depends on the RAP percentage and the properties asphalt binder in the RAP. Designers often rely on Table 2 from AASHTO M 323-12 (shown here as Table 5) to select the virgin asphalt binder grade.

In many cases involving Thinlays, relying on the AASHTO M 323-12 recommendations is acceptable. However, using AASHTO M 323-12 without knowing specific RAP properties may result in selecting a softer binder (lower temperature grade binder) than necessary (and the RAP may not stiffen the mix as much as assumed). Softer binders will generally be less resistant to rutting and shoving and more resistant to cracking. In cases where Thinlays will be placed over old cracked pavements that show little to no rutting or shoving (as is often the case), crack resistance should be emphasized.

If rutting or shoving is a concern, the appropriate recommendation for the low temperature grade can be followed, and the high temperature grade can remain (i.e., not be adjusted based on RAP percentage) or may be increased. The increased range caused by lowering the low temperature grade or raising the high temperature grade may necessitate a polymer-modified binder.

Asphalt binders are often modified with polymers to improve performance. Experience and research have shown that polymer-modified binders can improve many asphalt pavement attributes (e.g., resistance to cracking, resistance to rutting, and

Table 5. Recommended binder grade selection based on RAP percentage (AASHTO M 323-12)

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	<15
Select virgin binder grade one grade softer than normal (e.g., select a PG 58–28 if a PG 64–22 would normally be used)	15 to 25
Follow recommendations from blending charts	>25

Table 6. Aggregate gradation control points (AASHTO M 323)

Sieve Size (mm)	9.5 mm NMAS		4.75 mm NMAS	
	Min % passing	Max % passing	Min % passing	Max % passing
12.5	100	—	100	—
9.5	90	100	95	100
4.75	—	90	90	100
2.36	32	67	—	—
1.18	—	—	30	55
0.075	2	10	6	13

extended life). Polymer-modified binders have been shown to provide adequate rut resistance for areas with significant rutting potential (e.g., heavy or standing traffic), even in 4.75 mm NMAS mixes (Timm et al., 2013; West et al., 2012).

Polymer-modified binders are costlier, however, than standard performance-grade asphalt binders and are not always necessary. It is generally desirable to use polymer-modified binders in high traffic areas and in areas where existing pavements have moderate low-temperature cracking. It is also advantageous to use a polymer-modified asphalt when a Thinlay will be placed over a moderately cracked existing pavement. In every case, local availability must also be confirmed.

Mix Design

This guide discusses using the Superpave Volumetric Mix Design (Superpave) process and principles when designing Thinlay mixes. Even if a different or modified Superpave process is used in your area, the same principles will apply.

Materials and Aggregate Gradation

Superpave starts with material selection (e.g., aggregates and asphalt binder). As described above, material selection for Thinlays is very similar to material selection for conventional asphalt pavement.

The next step is selecting an appropriate NMAS and gradation (Table 6). Because Thinlays are placed thinner than conventional asphalt pavements, the NMAS may be smaller than what may be considered common in the area. Generally, compacted lift thickness should be no thinner than about three times the NMAS to allow for proper aggregate interlocking during compaction.

For example, a compacted ¾-inch Thinlay should have a NMAS of no more than ¼ inch (6.35 mm), and a 1-inch Thinlay should have a NMAS of no more than about ⅜ inch (9.5 mm). Although ⅜ inch is slightly more than ⅓ inch, such mixes compact well at 1 inch thickness.

Once the NMAS is selected, the gradation and trial asphalt binder content selection are the same as for conventional asphalt pavements. Typically, three different aggregate gradations are tested with a trial asphalt binder content in accordance with Superpave mixing, aging, gyratory compaction, and volumetric testing procedures.

Once each gradation's volumetric properties are calculated, the mix designer either selects the best gradation as the design aggregate structure or tests additional trial gradations. After the design aggregate structure is selected, further testing is performed at the applicable number of gyrations to determine the design asphalt binder content.

Important Superpave mix design parameters include the gyration level, air void percentage, voids in mineral aggregate, and dust to effective binder ratio.

Table 7. Gyration levels

Design ESALs (millions)	Compaction Parameters			Typical Roadway Applications
	$N_{initial}$	N_{design}	N_{max}	
<0.3	6	50	75	Very light traffic (local/county roads, city streets where truck traffic is prohibited)
0.3 to <3	7	75	115	Medium traffic (collector roads, most county roadways)
3 to <30	8	100	160	Medium to high traffic (city streets, state routes, U.S. highways, some rural interstates)
30 or more	9	125	205	High traffic (most of the interstate system, climbing lanes, truck weighing stations)

When specified by the agency and the top of the design layer is 100 mm or more from the pavement surface and the estimated design traffic level is 0.3 million ESALs or more, decrease the estimated design traffic level by one, unless the mixture will be exposed to significant main line and construction traffic prior to being overlaid. If less than 25% of the layer is within 100 mm of the surface, the layer may be considered to be below 100 mm for mixture design purposes.

When the design ESALs are between 3 million to less than 10 million ESALs the agency may, at its discretion, specify $N_{initial}$ at 7, N_{design} at 75, and N_{max} at 115, based on local experience.

Gyration Level

The gyration level corresponds to the compactive effort (expressed as a gyration number) applied to mix samples in the mix design process, and is intended to help predict how the mix will behave when traffic loading is applied. The more gyrations, the more the expected traffic. Superpave gyration levels are shown in Table 7.

Many states have modified the gyration levels to account for local conditions and performance desires. For Thinlays, except at high traffic levels (20-year design ESALs of 10 million or more), a gyration level of no more than 75 or 80 is appropriate. Higher gyration levels limit available gradations and tend to produce relatively stiff mixes that have less asphalt binder than mixes designed at lower gyration levels. Because Thinlays are preservation treatments, crack resistance (pavement flexibility) is typically preferred over stiffness.

Air Voids

Air voids (V_a) refers to the small air pockets between the asphalt-binder–coated aggregates in a compacted asphalt pavement. In the mix design process, the air voids are the air pockets that remain in mix samples after they have been compacted in the Superpave gyratory compactor. Calculating the percent air voids is critical for designers to determine how much asphalt binder to add to the mix. Once the design aggregate structure is selected, samples are prepared with different asphalt binder contents and the samples are then compacted at the applicable gyration level.

The samples with higher asphalt binder contents will have a higher percent compaction (more asphalt binder will fill some of the air voids and more air will get forced out of the mix when compaction effort is applied). For example, the sample with the lowest asphalt binder content might end up with 6% air voids (94% density), and the sample with the highest asphalt binder content might end up with 2% air voids (98% density).

After testing all samples and plotting the results, Superpave specifies selecting the asphalt binder content that the designer estimates will produce 4% air voids (96% density) at the specified gyration level. For Thinlays, to ensure crack resistance resulting from flexibility in the mix, the specified air voids may be adjusted to 3.5% with mixes that have performed acceptably at 4% design air voids.

Voids in Mineral Aggregate and Voids Filled with Asphalt Binder

Voids in mineral aggregate (VMA) refers to the void space between the aggregates in a compacted asphalt pavement. VMA is different from air voids because it includes the air pockets and the asphalt binder that coats the aggregates. For example, if the VMA of a compacted asphalt pavement is 14, and the percent air voids is 4, the remaining 10% of the space between the aggregates would be filled with asphalt binder.

VMA ensures the proper balance between air voids and asphalt binder, and helps mix designers develop asphalt pavement mixes that will perform acceptably. Generally, VMA for Thinlays is specified as a minimum of 15 and a maximum of 17 or 18.

Dust to Effective Binder Ratio

Dust to effective binder ratio refers to percent by mass of the material passing the 0.075 mm (No. 200) sieve (by wet sieve analysis) divided by the effective asphalt binder content (expressed as percent by mix mass). Superpave specifies an acceptable range of 0.6–1.2, with discretion to increase the ratio to 0.8–1.6 in certain situations. Smaller NMAS mixes (e.g., 4.75 mm) with dust to effective binder ratios toward the higher end of the acceptable range tend to be more resistant to rutting (West et al., 2011).

Typical Design Parameters

Typical Thinlay mix design parameters are shown in Table 8.

Table 8. Thinlay Mix Design Parameters

	¼" NMAS	⅜" NMAS
Design Method	Superpave	Superpave
Compaction Level	50–80 Gyrations	50–80 Gyrations
Air Voids % (V_a)	3.5%–4% (Max.)	3.5%–4% (Max.)
VMA %	15.0–18.0	15.0–17.0
P_{200}/P_{be} (dust to effective binder ratio)	0.8–1.6	0.8–1.6
Max. Binder Replacement	35%	35%

Special Volumetric Considerations

The VMA for 4.75 mm mixes tends to vary significantly between mixes. Mix designs conducted for materials in several states show high variability (Figure 24) (West et al., 2011). The VMA ranges from approximately 16 to approximately 22. With 4.75 mm mixes, it is not uncommon for the VMA to be significantly higher than the minimum VMA requirement of 16.0.

Higher VMA results in more asphalt binder being required, thus significantly increasing durability. However, if the minimum VMA is 16, then the maximum should not exceed 18.

Warm Mix

Warm mix technologies are acceptable for Thinlay projects (NAPA, 2008; Prowell et al., 2012). WMA technologies will allow more time for compaction, improve workability, and make achieving density easier, even if these technologies are not used to reduce production temperatures. However, warm-mix pavement production at reduced temperatures requires less fuel and heat than traditional hot-mix asphalt pavement, resulting in additional environmental and economic benefits.

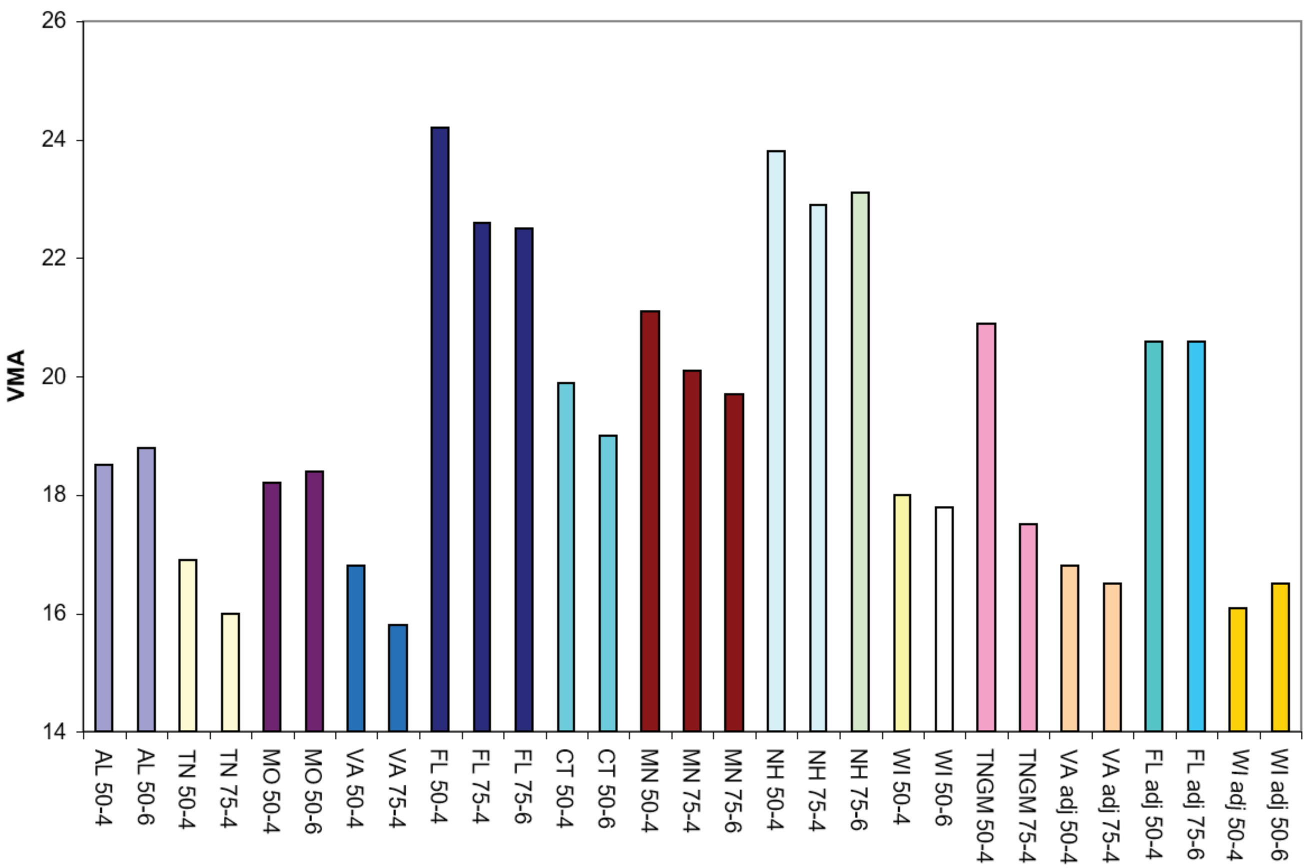


Figure 24. VMA Variation for 4.75 mm NMAS mixes (West et al., 2011)

7 Construction & Quality Control for Thinlays

Surface Preparation

Proper preparation of the existing surface is critical before Thinlay placement to ensure bonding between the Thinlay and underlying existing pavement. Bonding ensures that the final pavement section acts as a single structure rather than as independent layers. When pavement layers act as a single system, the pavement structure is significantly stronger than if they are not bonded together.

Investigate Existing Distresses

First, the entire existing surface should be visually inspected and distresses should be investigated. Once the distresses are quantified, the engineer should determine if individual distresses need repair, if pre-leveling is needed, and if all or specific areas of the existing surface will be milled. Recommendations on when to apply repairs and milling are set forth in Chapter 5: "Where to Use Thinlays." Where distresses are minor, Thinlays may be placed as an overlay without milling. If a Thinlay is placed as an overlay without milling, all durable pavement markings (e.g., thermoplastic) should be removed.

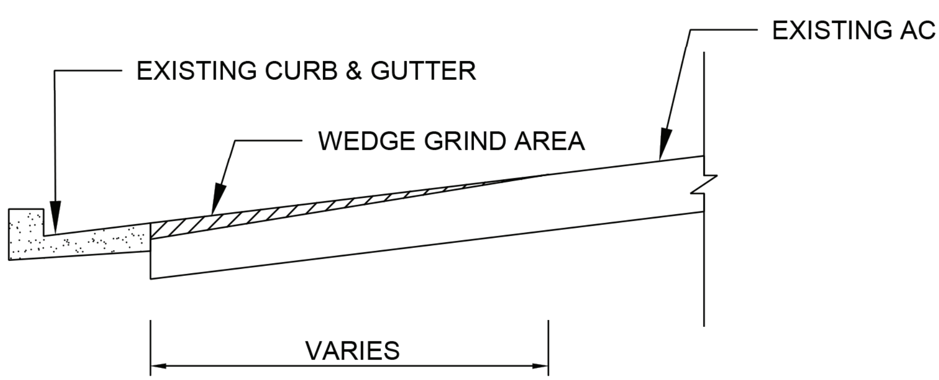


Figure 25. Taper milling cross section. The shaded wedge grind area would be the depth of the overlay at the curb edge.

In cases where distresses are minor but gutter and curb elevations must match the existing elevation, taper milling (milling only in areas where the finished elevation must match the existing elevation and tapering to the existing pavement surface) may be less expensive than milling the entire pavement surface at a constant depth.

However, where the taper milling width is less than the paver width (because pavers cannot typically vary cross slope) the pavement depth will vary with the existing surface slopes, and will be thinnest at the point where the taper mill meets the existing pavement surface and deepest at the curb edge (Figure 25). In such cases, the minimum Thinlay thickness must be maintained where the taper milling meets the existing pavement surface.

It is typically preferable to avoid variable thickness application in a surface course by increasing the cross slope across the width of at least one paver pass rather than to create a low point by taper milling a width less than the paver width.

If patches, such as from utility cuts, are present and in good condition, a Thinlay can be placed on top of the patched pavement. If the patch is in poor condition or the subgrade is unstable, a more permanent repair should be made prior to placing an overlay. If the area is raised or depressed, the patch area should be milled or leveled accordingly. It is possible for the edges of patches to reflect through an overlay over time, similar to reflecting cracking.

If the existing surface will not be milled, the milling section below does not apply, but the cleaning and tack coat sections do.

Milling

If the existing surface will be milled, the milling depth should be the minimum needed to correct any distresses in the existing surface. The three primary categories of milling are standard, fine, and micro milling. These categories refer to the horizontal spacing of the teeth on the cutter drum of the milling machine. Standard milling refers to 15 mm (5⁄8 inch) spacing; fine milling refers to 8 mm (5⁄16 inch) spacing; and micro milling typically refers to any spacing less than 8 mm.

The type of milling depends on project-specific factors. Contractors have successfully placed Thinlays on each type of milled surface. In fact, the milling equipment condition, the existing asphalt pavement condition, and layer thicknesses, as well as the milling machine speed relative to the cutter drum rotation speed, are more important than the type of milling.

As milling depth increases, the energy required to fine or micro mill increases significantly. Fine or micro milling at depths greater than about 1½ to 2 inches requires significantly more energy than standard milling and will be slower and significantly more expensive. At shallower depths, the energy to fine or micro mill is comparable to that of standard milling and there is less difference in cost, assuming fine or micro milling equipment is available.

With respect to the existing asphalt pavement, the NMAS and the layer thickness must be considered. Most cutting drums pull aggregates out of the existing asphalt pavement (as compared to cutting through them). When pavements with a NMAS of greater than ½ inch are milled, the difference in the resulting texture among the different types of milling will be less significant. With ½-inch or less NMAS asphalt pavements, fine and micro milling will provide a smoother surface that will be less likely to cause bumpiness in the finished Thinlay surface.

Figure 26. Scabbing

Also, milling close to the depth of an asphalt pavement layer (e.g., milling 1½ inches of a 2-inch-thick asphalt layer with a ½-inch NMAS), will often result in pattern inconsistencies (sometimes referred to as "scabbing") in the milled surface regardless of the type of milling used (Figure 26). In some areas, the entire layer may be milled, and in others, some of the layer may remain, causing variations in the surface that may result in bumpiness in the finished Thinlay surface.

If the layer thicknesses of the existing pavement are known, or if scabbing is apparent in milled areas, it is beneficial to change the milling depth to either mill entire layers (mill deeper) or leave more thickness in any existing layer than the NMAS (mill shallow enough that there is no scabbing).

The condition of milling equipment greatly affects the consistency of the resulting pattern. Well-maintained cutter drums will have consistent tooth wear and will produce a uniform pattern within recommended operating speeds. The speed of the machine must also be balanced with the cutter drum rotation speed, in accordance with manufacturer recommendations.

As the cutter drum rotates, the teeth strike the pavement surface. If the cutter drum rotation speed is held constant and the milling machine speed is reduced, there will be more strikes per foot and a finer pattern. In many cases, a standard milling machine can produce a pattern comparable to that of fine milling by simply slowing the machine speed.

If the pattern of the milled surface is inconsistent, the milling machine speed should be monitored and the cutting teeth should be checked for excessive or inconsistent wear. If milling speed and cutting teeth condition are acceptable, the existing pavement condition should be investigated. Fine or micro milling may produce a more uniform pattern in cases where the surface produced by standard milling would be inconsistent because of existing pavement conditions.

Thinlay milling should produce a consistent texture with ridge-to-ridge distances and ridge-to-valley depths of no more than ¼ inch. Fine or micro milling will typically produce ridge-to-ridge and ridge-to-valley distances of less than ¼ inch. Although many existing pavements with shallow distresses may benefit from fine milling, an acceptable pattern may be achieved with proper standard milling. Greater focus should be on producing a consistent pattern than the type of milling.

Cleaning

Do not overlook cleaning. A dirty surface will prevent an adequate bond between the Thinlay and the existing pavement. The existing surface should be cleaned by sweeping or washing. More than one pass of a sweeper across the entire existing surface is typically needed, especially after milling. If the surface is washed, the existing pavement must dry before placing the Thinlay.

Tack Coat

After completing repairs, milling (if used) and cleaning, follow standard accepted practices for applying a tack coat prior to Thinlay placement. The tack material (e.g., asphalt emulsions, cutbacks, or hot-sprayed asphalt binder) should have a history of successful use in the area within the applicable temperature range.

Although the proper tack material quantity depends on the condition of the existing pavement surface (e.g., rough surfaces typically require more tack material than smooth surfaces) and the type of tack material used, the residual tack on the existing surface after application (the material remaining after evaporation of any water and the material has set) should evenly cover not less than 90% of the existing surface to be paved. The distributor should be checked during tack coat application to ensure the spray bar is at the correct height, spray is identical from each nozzle, and that the spray from each nozzle overlaps by 50% (except for the spray from the nozzles on either distributor bar end). There should be no streaks or large or repeated bare spots. Too much tack should also be avoided because it can also prevent an adequate bond. A shiny and thick appearance or pooling indicates too much tack.

If a Thinlay is used as an overlay in rutted areas, the tack material must not pool in the rutted areas. See Chapter 5 for recommendations concerning rutting.

Milled surfaces have more surface area per square yard than non-milled surfaces (due to the ridges). The amount of additional surface is typically about 20% or 30%, which requires a corresponding increase in tack material. For detailed information on tack coat material see *Best Practices for Emulsion Tack Coats* (QIP-128) from the National Asphalt Pavement Association (Decker, 2013).

After the tack coat has been applied, but before the Thinlay has been placed, precautions should be taken to minimize the potential for tracking of the tack (i.e., tack sticking to truck and equipment tires). Precautions should include: not applying tack until all repair areas have been completed and the existing surface has been cleaned; preventing traffic from driving on areas that have been tacked; and preventing trucks and construction equipment from driving on areas that have been tacked until after the tack coat has set (typically when all water in the tack material has evaporated) or cured.

Production & Paving

Thinlay production and paving practices are not substantially different from those of conventional asphalt paving. With respect to production, it is important to monitor aggregate and RAP moisture content, because Thinlays utilize finer aggregates and RAP materials than conventional asphalt pavement mixes and the finer materials retain more moisture. Excess moisture should be removed during the heating and mixing process.

If polymer-modified asphalt binders are used, the paving crew must be told because the mix will stiffen quicker and have less workability than typical. As polymer modification increases, workability and compactibility decrease.

Also, because Thinlays are placed thin, it may be possible to operate the paver faster than normal, which may make it hard for the rollers to keep up. The production rate may have to be reduced or rollers may need to be added to allow for satisfactory Thinlay compaction.

Compaction

As with all asphalt pavements, proper compaction is critical. Although the same compaction principles apply to Thinlays as for thicker asphalt pavements, the thinness affects the compaction process. Thinlays will cool more quickly than thicker pavements, which means there is a smaller window of time for compaction, but less compaction energy is required because of the thinness. Warm-mix technologies can be used to extend the time for compaction, if necessary.

Contractors should operate steel-wheeled rollers in static mode close to the paver and cover the entire surface area at least twice before finish rolling. Rollers should only operate in vibratory mode if a test area shows that doing so will not over-compact the mix by crushing aggregates or causing the mix to shove or become rough or unstable. Pneumatic (rubber-tired) rollers should be prohibited.

MultiCool is a free mobile app and desktop software offered by the National Asphalt Pavement Association that helps estimate the time available for compaction. It can be downloaded from: *www.asphaltpavement.org/multicool*.

Quality Assurance

Quality assurance for asphalt paving includes planned and systematic inspections, with sampling and testing to provide confidence that the asphalt pavement will perform satisfactorily. Quality control is a part of quality assurance and typically includes sampling and testing performed by the contractor to monitor its operations. Acceptance sampling and testing is often, but not always, performed by the owner or agency to determine whether or not the asphalt pavement is acceptable.

The quality assurance measures for material quality and mix production for Thinlays are the same as for conventional asphalt paving. The asphalt pavement mix producer's quality control technicians should sample and test aggregate, as well as RAP and RAS stockpiles for moisture. Because Thinlays use finer aggregate gradations and finer RAP and RAS materials, and because finer aggregates and RAP retain moisture longer, the asphalt plant may need to be adjusted to account for higher than normal moisture.

The quality control technicians should also sample and test the production mix and monitor its moisture, asphalt content, gradation, and volumetrics. Although volumetric testing will differ among states, it should generally include voids, voids in mineral aggregate, and dust to effective binder ratio. Quality control sampling and testing should be conducted at a reasonable frequency, such as every 1,000 tons of produced asphalt pavement or daily. State departments of transportation typically publish sampling and testing requirements and guidance that should be used where applicable.

Although much of the quality control and assurance testing for Thinlays is the same as for conventional paving, density testing and smoothness are different. The primary methods for testing density are testing cores and taking readings from a nuclear gauge. Neither, however, should be used for Thinlays.

Testing Thinlay cores for density often produces inaccurate results because the cores are frequently damaged during coring or sample preparation. Nuclear density gauges should also not be used to test Thinlay density because the gauges test deeper than Thinlay thicknesses and the results will be substantially influenced by the existing asphalt pavement under the Thinlay.

Although nuclear gauges cannot be used to accurately measure Thinlay density, they may be used to develop a roller pattern. At the beginning of a Thinlay project, after the paver has placed the asphalt pavement, the asphalt pavement temperature and a nuclear gauge reading is taken at locations within the test area before rolling and after each roller pass.

Although the nuclear gauge measurements will not reflect accurate density measurements, the readings can be used to roughly determine the increase in density caused by each roller pass and the number of passes at which the density reaches its maximum level.

If there are no visible problems with the compacted asphalt pavement (e.g., shoving, tearing, or crushed aggregate), the roller pattern that produced the maximum density readings should be repeated throughout the project. For most Thinlays, 8-ton steel-wheeled rollers should cover the surface area of the pavement at least twice while the pavement is within the temperature range for compaction for the asphalt binder.

If a nuclear gauge is unavailable or if it is otherwise determined that a roller pattern is unnecessary (e.g., in cases in which the contractor or agency has experience with the Thinlay mix), it is generally acceptable to simply ensure that the 8- to 10-ton steel-wheeled rollers cover the entire surface area of the Thinlay at least twice while the asphalt pavement is above the minimum compaction temperature for the asphalt binder used.

Any smoothness requirements must account for the smoothness of the existing pavement, especially if the existing pavement will not be milled prior to placing the Thinlay. Although Thinlays will improve the smoothness more than most other pavement preservation treatments, their ability to do so is less than that of thicker asphalt pavement lifts.

8 Life-Cycle Cost Considerations

Life-cycle cost analysis (LCCA) attempts to identify the best value (lowest long-term cost that meets the performance requirements) among infrastructure investment alternatives. A complete explanation of LCCA is beyond the scope of this guide, but these general principles can be used to compare pavement preservation treatment alternatives.

Preservation (not just for roads) is integral to LCCA because proper preservation is often performed before visible distress occurs, increasing the useful life of infrastructure and reducing costs over the life of an asset. In other words, LCCA helps agencies confirm that they are using public money effectively.

LCCA does not account for improvements in level of service or sustainability benefits, however, and its accuracy is highly dependent on the accuracy of the information used in the analysis. Some agencies may place significant value on ride quality or noise reduction because such issues are important to road users, and others may have made commitments to maximize the use of recycled materials and reduce fuel usage. Such agencies may choose to not use LCCA, or may use LCCA as one factor in the decision-making process.

LCCA generally requires estimating the initial cost of alternatives, creating a schedule of future activities associated with each alternative, estimating the cost of the future activities, estimating the cost impact on the users (e.g., local commuters and businesses), calculating the present dollar value of the future costs (to the agency and user) by using a discount rate, and assessing risks and other concerns.

Initial costs should be estimated from unit prices from recent pavement preservation projects. It is important to consider similar projects. For example, the unit price of asphalt pavement on a very small project or on a project where asphalt was only a small part of a larger project may not be representative for a larger Thinlay project. Calculating the average cost over an entire season or two helps avoid non-representative initial cost estimates.

Estimating future activities requires selecting an analysis period (i.e., how far into the future to consider) and predicting the life of the preservation treatment alternatives. The analysis period should be long enough to capture at least one major rehabilitation or reconstruction, which for roads is often more than 30 or 40 years.

Predicting the life of the preservation treatment alternatives requires agencies to analyze past experience with different treatments, which may include referring to historic pavement condition ratings (PCRs) and pavement performance curves. If an agency does not have experience with Thinlays, the case studies included in this guide or the information included in the SHRP 2 report (Peshkin et al., 2011) showing a benefit of 12 years or more may be used as a starting point.

Predicting the life of preservation treatment alternatives is one of the most difficult steps in pavement preservation LCCA. The life of a pavement preservation treatment is dependent on the condition of the pavement on which the treatment is placed. Agencies simply cannot precisely predict how long a treatment will last if placed on a pavement with 10%, 20%, or 30% surface cracking because it is rare to have examples where the same preservation treatment was used with the same level of distress. Accordingly, agencies should recognize that LCCA results within a range (e.g., within 10%) may be essentially equal because of inaccuracies in predicting life.

Salvage value (also called remaining service life value) accounts for the fact that the asset will continue to serve beyond the analysis period. It is an estimate of the value of the asset at the end of the analysis period. Salvage value is important when analyzing Thinlays because Thinlays will often extend the structural life of a pavement section more than other common preservation treatments, thus increasing the salvage value.

User costs should also be included in LCCA to account for costs incurred by the users of the road. User costs typically include vehicle operation and repair, travel time or delay, and crash costs. User cost factors include the timing, duration, scope, and number of work zones throughout the analysis period. User costs are often less for alternatives that require shorter or fewer traffic restrictions. For example, assume Treatment Alternative 1 will last for 10 years and requires one road lane to be closed per day over a four-day period. Assume Treatment Alternative 2 will last for five years and requires the same road lane closure period. Treatment Alternative 2 will have higher user costs over an analysis period of more than 10 years because users will be affected by the required work zone activities for more overall time. Thinlays often have less user costs because Thinlays will have no cure time and often have fewer future traffic restrictions than other pavement preservation alternatives.

Applying a discount rate accounts for the time value of money. It is necessary to account for the opportunity value of time when comparing costs that will occur at different times. The discount rate accounts for the economic return that could be earned on money in its next best alternative use (e.g., the money could be earning interest). The discount rate is typically 3–5%, with 4% being the most common rate, which represents the prevailing rate of interest on borrowed funds, minus inflation. LCCA requires future costs to be expressed in constant dollars and then discounted to a present value.

For more details on proper use and application of LCCA, consult the FHWA's *Life-Cycle Cost Analysis Primer* (FHWA, 2002) and OMB Circular No. A-94 Revised (OMB, 1992).

Pavement cores from 2016 Thinlay project in Darke County, Ohio.

9 Thinlay Case Studies

NCAT Pavement Test Track

The National Center for Asphalt Technology at Auburn University (NCAT) is fully equipped with state-of-the-art laboratory and field testing equipment. NCAT has evaluated numerous 4.75 mm NMAS asphalt pavement mixes in the laboratory and field. The NCAT Pavement Test Track is a 1.7-mile oval divided into different test sections to analyze how asphalt pavement performs under loading. NCAT operates weighted trucks on the test track and applies 10 million equivalent single axel loads (ESALs) to the test track every two years. The laboratory and test track allow for precise evaluation of asphalt pavements and paving techniques.

In 2003, the Mississippi Department of Transportation (MDOT) sponsored placement of a ¾-inch thick 4.75 mm NMAS asphalt pavement mix on the NCAT Test Track to determine if a thin asphalt pavement inlay or overlay would perform acceptably under heavy traffic (Section W6 in Figure 26). The mix consisted of 69% limestone, 11% natural sand, 19% crushed gravel, and 1% lime. NCAT designed the mix in accordance with the Superpave process using 50 gyrations and selecting the asphalt binder content at 4% air voids, which resulted in a binder content of 6.1%. The VMA was 16% and the asphalt binder grade was PG 76–22.

To date, the mix has been subjected to more than 40 million ESALs over a 14-year period (an extremely high traffic level). The average rutting is 7 mm, and the International Roughness Index (IRI) has increased from 45 to 60, indicating minor rutting and a minor increase in roughness. There is no cracking.

As a result of the fantastic performance, the MDOT now uses thin 4.75 mm NMAS mixes as one of its primary pavement preservation treatments. Because of the results, other states, such as South Carolina, now also use thin 4.75 mm NMAS mixes for pavement preservation. Similarly, North Carolina uses more 9.5 mm NMAS mixes than larger aggregate 12.5 mm NMAS mixes, which allows it to reduce layer thicknesses in its preservation overlays and inlays by approximately 25%.

Several states also sponsored NCAT research on 25 different pavement preservation treatments on

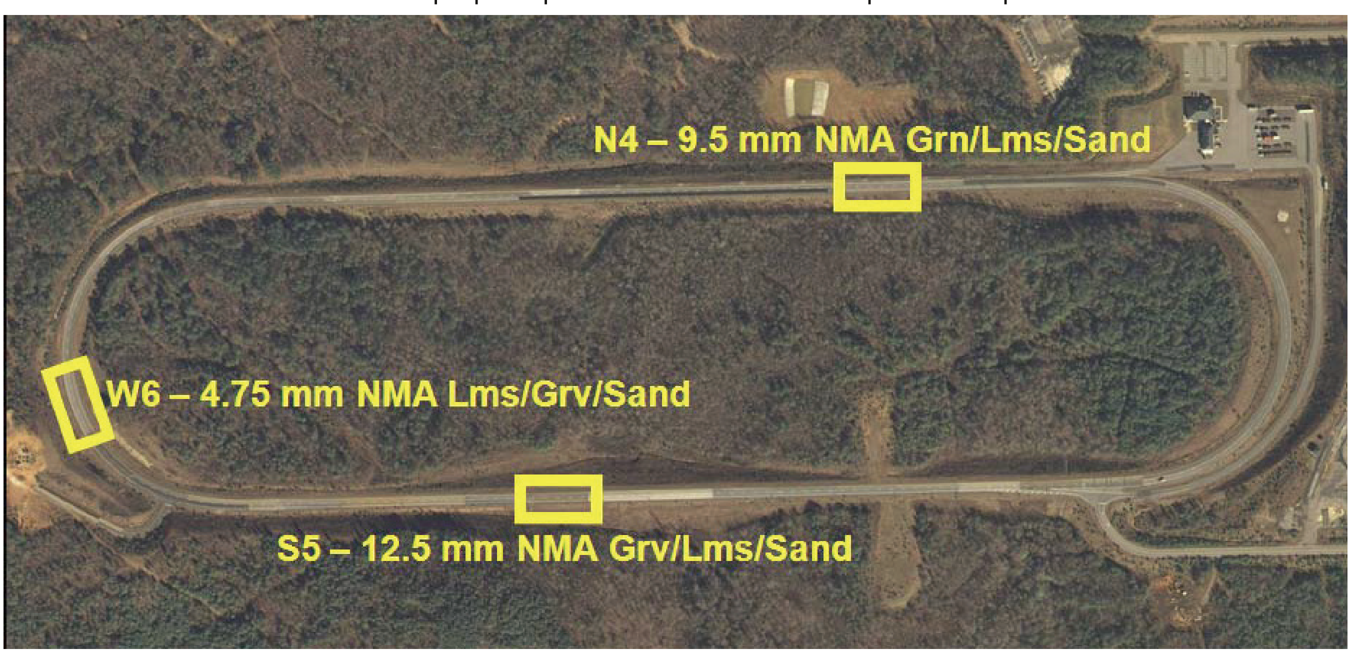


Figure 26. Location of MDOT comparison sections on the NCAT Pavement Test Track (Powell & Buchanan, 2012).

a county road near NCAT. The treatments include Thinlays, chip seals, microsurfacing, and crack sealing, and were placed on the road in 2012, when the two-lane county road was 10 years old and in good condition. The road was selected because it connects a quarry to a highway, with loaded trucks using the lane leaving the quarry and empty trucks use the lane returning to the quarry. This allows for a performance comparison under significantly different loading.

To date, the Thinlay sections have performed well, but it is too soon to reach any conclusions. NCAT is continuing to monitor performance and intends to publish preliminary findings after 2020.

In 2015, the same preservation treatments were placed on a highway close to NCAT for evaluation under higher-volume traffic. Additionally, in 2016, the preservation treatments were constructed on similar sites in Minnesota near the Minnesota Department of Transportation's MnROAD pavement test track for evaluation in a colder climate. The findings will be published and posted on the NCAT website as reports are completed.

Oregon Experience

Murray Boulevard in Beaverton, Ore., is a major arterial best known for its access to Bowerman Drive — the main entrance to Nike World Headquarters, where thousands of employees work on a sprawling campus. To asphalt pavement engineers, Murray Boulevard is important not because of its famous tenant, but because of its sections of thin asphalt pavement.

The first section (about 2,700 feet) of 1-inch thick asphalt pavement was paved in 2001 after Washington County noticed cracking in the existing surface (Figure 27). Washington County extended the 1-inch section another 2,200 feet in 2002. The mix was a 100 gyration, 9.5 mm NMAS mix, with PG 64–22 asphalt binder, and no reclaimed asphalt pavement. The records show that the contract price was $40 per ton.

As of 2017, Washington County sealed cracks and performed minor maintenance, but has performed no significant resurfacing on the initial thin-lift pavement sections.

In 2007, Washington County needed a preservation treatment to extend the life of a much larger section of Murray Boulevard by least 10 years. Funding was too low for a major rehabilitation, but something was needed to stop acceleration of fatigue cracking.

A chip seal was unsuitable because of high traffic volume, and other seals did not provide the needed life. The county's engineers decided to overlay the existing surface with thin-lift paving as done in 2001 and 2002.

Figure 27. Thinlay placed in 2001; photo taken June 2017

They specified a 1-inch thick section of Level 3 (100 gyration) 9.5 mm NMAS mix, with PG 64–22 asphalt binder and no RAP, for over 2 miles of Murray Boulevard (approximately 788,000 square feet), which required about 4,800 tons of asphalt mix (Figure 28). Recognizing that there was no way to accurately measure the density of a 1-inch lift, the county did not specify a specific density requirement and instead required compaction "as directed."

Baker Rock Resources of Beaverton, Ore., was awarded the project with a bid price of $46.70 per ton of placed asphalt pavement, which was applied to an estimated quantity of 4,797 tons, for a total contract price of about $224,000. Baker Rock Resources developed the mix design shown in Table 9.

Baker Rock tested the mix for rutting potential with the local pavement association's Asphalt Pavement Analyzer. Oregon's typical maximum allowed rutting for samples tested with the Asphalt Pavement Analyzer is 6 mm, and all the samples tested well under the limit at less than 3 mm.

Because of significant daytime traffic, Baker Rock completed the paving at night, averaging just over 1,000 tons per night. Paving 1 inch with lower night temperatures necessitated tarping the trucks and running the breakdown roller close to the paver. Baker Rock targeted four roller passes with steel-wheeled rollers operated in static mode for compaction.

Because Baker Rock was concerned about getting compaction with cooler nighttime temperatures and thin paving, it added additional asphalt binder during production. Although additional asphalt binder could increase the risk of rutting, the rut tests showed that the mix was sufficiently stable. The first night Baker Rock produced mix at 6.57% asphalt binder, and increased that percentage to around 7% for the remaining nights of paving. The actual quantity of asphalt pavement placed was 4,730 tons, for a total contract price of $220,892, which calculates to about $2.63 per square yard.

All the sections performed exceptionally through 2016. However, the 2016–17 winter was one of the worst on record for Washington County (it was the coldest winter in the Pacific Northwest since 1992–93, with four ice storms and four snow events), which caused the surface to show signs of failure with some cracking and areas of delamination. Washington County plans to spot repair the failures over the 2017 paving season and repave in 2018.

The 2001 and 2002 sections provided over 15 years of service with little maintenance (some crack sealing), and the 2007 section provided 10 years of maintenance-free service. With respect to the 2007 section, it is likely that the durability was due to the additional asphalt binder Baker Rock added to the mix. Without knowing it at the time, Baker Rock essentially did what the Asphalt Pavement Association of Oregon recommends for pavement preservation:

Table 9. Murray Boulevard mix design from 2001

Gradation		
Sieve	Target Percent Passing	Tolerance
½"	100	100
⅜"	92	90–100
No. 4	68	90 Max.
No. 8	40	36–44
No. 30	17	13–21
No. 200	6.6	4.6–8.6
Asphalt Binder (PG 64–22)		
Target Percent	Tolerance	
6.1	5.6–6.6	

Figure 28. Thinlay placed in 2007; photo taken June 2017

designing for durability with additional asphalt binder if rut testing shows adequate stability.

Thinlays provided Washington County an affordable and dependable preservation treatment that extended the life of a critical urban arterial well beyond the typical 3–5 years of additional life provided by chip or other seals.

Had the county used a chip or other seal, maintenance would have been required more often, and the underlying pavement would not have had the structural benefit of an additional inch of asphalt pavement.

After Murray Boulevard was paved, a consultant recommended microsurfacing to preserve the county's arterials. After a couple of seasons of inconsistent performance and delays in opening microsurfaced sections to traffic, the county switched back to thin asphalt pavement treatments. Baker Rock Resources paved another 1-inch-thick asphalt overlay on SW 170th Street (another major arterial in Washington County) in 2015, and it looks and rides great as of October 2017.

None of the Thinlays have failed prematurely, and the recently paved Thinlays are expected to last at least as long as the Murray Boulevard sections.

Michigan Experience

Agencies in Michigan have experience as far back as the 1990s with what is referred to locally as "Ultra-Thin HMA," which is asphalt pavement overlays and inlays designed for ¾- to 1-inch placement thickness.

The NMAS for these mixes is 4.75 mm to 6.4 mm, and the asphalt binder grade is PG 64–22 or 64–28 for low-volume applications (less than 380 average daily traffic (ADT)) a polymer-modified PG 64–28 for medium-volume applications (380 to 3,400 average ADT), and a polymer-modified PG 70–22 or 70–28 for high-volume applications (more than 3,400 ADT).

Table 10. Ultra-thin statistics (number of jobs, length, and age)

Ultra-Thin Type	Traffic Level	# of Jobs	Length (miles)	Average Age
Ultra-Thin Low	< 380 ADT	52	483	8.6
Ultra-Thin Med.	380–3400 ADT	41	339	6.6
Ultra-Thin High	> 3400 ADT	16	89	6.4

Table 10 contains general information gathered by the Asphalt Pavement Association of Michigan (APAM) on the extent of use and performance of Ultra-Thin HMA in Michigan.

Over 100 projects have been completed on more than 100 miles of road, with the average age of the treatments varying from 6.4 to 8.6 years and many remaining in service to date, which means the service life will exceed the average age shown in Table 10.

Table 11 contains information gathered by the APAM and the Michigan Department of Transportation (MDOT) on initial cost and expected life of common Michigan preservation treatments. As shown, the average cost per square yard per year of an Ultra-Thin HMA is less than that of a chip seal or microsurfacing.

At the local level, the City of Mount Pleasant, Mich., has consistently used Ultra-Thin HMA for pavement preservation since 2000, and Flint incorporated Ultra-Thin HMA as one of its primary pavement preservation treatments in 2004.

Both cities are pleased with the performance of Ultra-Thin HMA and continue to use them as a primary pavement preservation technique.

Table 11. Preventative Maintenance Treatment Cost Comparison (2016)

Treatment	\$ Per Yd²	Life Extension Range	Average Life Extension	Average Cost per Yd²/Year
Double chip seal	$3.18**	3–5**	4**	$0.80
Microsurfacing	$2.61**	3–5**	4**	$0.65
Ultra-Thin Low	$2.51**	5–9*	9*	$0.28
Ultra-Thin Med.	$2.87**	5–9*	8*	$0.36
Ultra-Thin High	$3.29**	5–9*	7*	$0.47

*Estimated by APAM; ** Estimated by MDOT

Ohio Experience

The Ohio Department of Transportation (ODOT) and Flexible Pavements of Ohio (FPO) developed a thin asphalt preservation treatment similar to Thinlays called Smoothseal™ in the 1990s. About 3 million tons of the material has been placed in Ohio since 2002 on everything from interstates to bike paths.

There are two types of Smoothseal: Type A is purely a sand asphalt mix with an 8.5% asphalt binder content, and Type B is a ½-inch NMAS mix with typical asphalt binder content around 7%. Both use polymer-modified asphalt binders. Type A Smoothseals vary in thickness from ⅝ to ¾ inch, and Type B Smoothseals vary in thickness from ¾ to 1 inch.

Table 12 shows the number and type of pavement preservation projects utilized by ODOT from fiscal years 2015 to 2018. As shown, ODOT has significantly increased the use of Smoothseals. Figure 29 shows the cost per lane mile for different pavement preservation treatment options based on 2016 ODOT cost data and an average cost of 2017 Ohio Thinlay projects.

Table 12. ODOT pavement preservation projects fiscal years 2015–2018

Preservation Type	FY2015		FY2016		FY2017		FY2018†	
	# of Jobs	Lane Miles	# of Jobs	Lane Miles	# of Jobs	Lane Miles	# of Jobs	Lane Miles
Microsurfacing	13	367	52	1,016	39	1,062	48	1,361
Chip Seal	15	219	25	333	31	638	17	278
Smoothseal (A & B)	9	199	47	919	111	2,039	103	1,577

†As of June 14, 2018

The City of Englewood, Ohio, started using Smoothseals for pavement preservation in 2002 and has seen great performance for more than 12 years. Englewood's experience lead the city to conclude that higher initial Smoothseal cost is a worthy investment due to the savings realized over the life of the pavement. The city boasts that all the roads under its jurisdiction have Smoothseal surfaces.

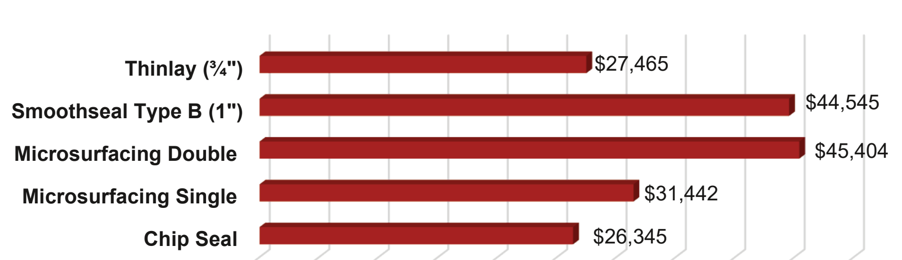
In 2015, an additional Thinlay specification was developed as an alternative to microsurfacing and chip seals for roads ranging from moderate to ultra-light traffic conditions. Binder selection and aggregate angularity is the key to the Thinlay mixture's ability to achieve successful performance under these extremes.

Similar to Smoothseal, Thinlay has a fine texture to ensure a uniform mat surface free of segregation. The difference is that Thinlays include 70% fine aggregates (passing the No. 4 sieve) compared to 85% for Smoothseals. The mixes also differ in binder grade selection. Smoothseal uses only polymer-modified PG 76–22. Thinlays, however, tailor the binder type to traffic intensity, using a range of binders from polymer-modified PG 70–22 for heavier traffic all the way down to PG 52–28 for ultra-light conditions. Most Thinlays have been placed on light and ultra-light traffic roads; all at ¾-inch thicknesses.

Darke County was the first county in Ohio to experiment with Thinlay, and the material has become the county's mix of choice. In Ottawa County, the Village of Genoa chose a medium-traffic design using PG 64–22 binder to pave 5 miles of Clay Center Road.

2018 will see Thinlays constructed on ODOT projects in five districts, and more are scheduled for the 2019 construction season as ODOT ramps up the use of Thinlays as part of its extensive asset management initiative.

Figure 29. Initial cost per lane mile



Initial cost based on complete schedule of work to place the treatment, assuming 1% partial depth repair, as well as tack coat (for Thinlay and Smoothseal) and removal of lane markings for chip seals and removal of raised pavement markers and lane markings for microsurfacing.

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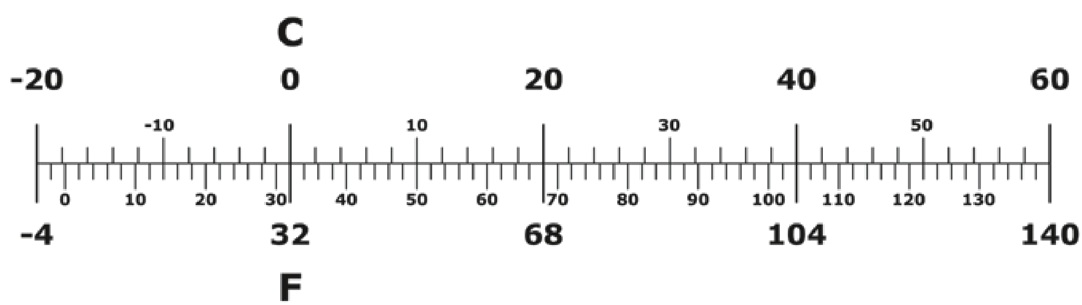
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSION TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	645.2	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L should be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lbs	pounds	0.454	kilograms	kg
T	short tons	0.907	megagrams	Mg
T	short tons	0.907	metric tonnes	t
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°F	Fahrenheit	$\frac{5(F-32)}{9}$	Celsius	°C

APPROXIMATE CONVERSION FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lbs
Mg	megagrams	1.102	short tons	T
t	metric tonnes	1.102	short tons	T
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°C	Celsius	(1.8×C)+32	Fahrenheit	°F



*SI is the symbol for the International System of Units

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