TOPS

Targeted Overlay Pavement Solutions

Crack Attenuating Mixtures

How-To Document

March 2022

U.S. Department of Transportation
Federal Highway Administration

Every Day Counts
Innovation for a Nation on the Move

NOTICE

NON-BINDING CONTENTS

QUALITY ASSURANCE STATEMENT

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This document highlights FHWA's Every Day Counts initiative known as Targeted Overlay Pavement Solutions. TOPS integrates innovative overlay procedures into practices to improve performance, lessen traffic impacts, and reduce the cost of pavement ownership.
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16. Abstract
Crack Attenuating Mixture (CAM) interlayers contain high asphalt content using a modified binder and are utilized in hybrid overlay systems. Other typical characteristics of CAM include quality virgin aggregate, fine gradations, and performance testing for crack mitigation and rut resistance. CAM is placed as an interlayer under both thin and thick surface lifts.

The Texas Department of Transportation (TxDOT), New Jersey DOT (NJDOT), and Nevada DOT (NDOT) have used CAM and other similar products, including Thin Overlay Mixture-Fine (TOM-F), Binder Rich Intermediate Course (BRIC), and Engineered Stress Relief Course (ESRC) to mitigate cracking on both asphalt and concrete surfaces. This document describes DOT experiences with these products and includes considerations for project design and planning, mixture and material selection, and construction specifications.

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LIST OF ACRONYMS

AASHTO	American Association of State Highway Transportation Officials
APA	Asphalt pavement analyzer
BRIC	Binder rich intermediate course
CAM	Crack attenuating mixture
CRCP	Continuously reinforced concrete pavement
DOT	Department of transportation
ESRC	Engineered stress relief course
FDR	Full-depth repair
HMA	Hot mix asphalt
HWTT	Hamburg Wheel Tracking Test
IC	Intelligent compaction
JPCP	Jointed plain concrete pavement
LCCA	Life cycle cost analysis
MTV	Material transfer vehicle
NMAS	Nominal maximum aggregate size
PG	Performance grading
PMTP	Paver-mounted thermal profiler
SAC	Surface aggregate classification
SDI	Surface distress index
SMA	Stone matrix asphalt
TOM	Thin overlay mixture
WMA	Warm mix asphalt

INTRODUCTION

Crack attenuating mixture (CAM) interlayers are part of a hybrid overlay system. Reflective cracking is a concern for many rehabilitation projects. Cracks typically migrate upward approximately 1 inch per year through conventional overlays (Blankenship 2019). Properly designed CAM interlayers can reduce the number of reflective cracks and slow the rate of reflective cracking by up to 50 percent (Blankenship 2019). Typical CAM characteristics include (FHWA 2021):

- High asphalt content using modified binder (typically around 7 percent).
- Quality virgin aggregate.
- Fine gradations (typical nominal maximum aggregate size of the No. 4 to 3/8-inch sieve).
- Performance tested for crack mitigation and rut resistance.
- Applied in thin lifts of 0.5 to 1 inch.
- Placed as an interlayer in an overlay system.

One of the first crack relief interlayers, or CAM products, was a proprietary product designed and marketed in the late 1990s. The product was originally designed for structurally sound jointed plain concrete pavement (JPCP) with doweled joints in good condition (Bischoff 2007). Shortly after this proprietary product was introduced, several State departments of transportation (DOTs) created versions of CAM.

For example, the Texas Department of Transportation (TxDOT) evaluated the proprietary product and reported excellent reflective cracking mitigation properties based on laboratory and field results (Scullion and Von Holdt 2004). However, TxDOT found that the highly flexible mix was very soft and had poor rutting properties, according to laboratory results. If placed underneath a thick lift of hot mix asphalt (HMA) surface lift, the poor rut resistance may not have been problematic. However, many TxDOT districts reported an urgent need for an overlay solution for urban areas with a maximum overlay thickness of fewer than 3 inches. Additionally, staged construction often involves opening intermediate lifts to traffic well before the surface lift is placed, and hot Texas temperatures exacerbated rutting concerns during these staged construction projects. Therefore, TxDOT developed a CAM specification with both crack and rut resistance performance testing.

CAM Terminology

Many DOTs have developed mixtures to serve as crack relief interlays; however, they are often called something other than CAM. Table 1 summarizes the DOTs and CAM products described in this document. The table represents agencies that have had success mitigating reflective cracking using these layers.

Table 1. DOT CAM Products Summary (TxDOT 2014, TxDOT 2017, NJDOT 2018, Warrag and Hajj 2020).

DOT	CAM Product Name
TxDOT[1]	CAM Thin Overlay Mix-Fine (TOM-F)
New Jersey DOT (NJDOT)	Binder Rich Intermediate Course (BRIC)
Nevada DOT (NDOT)	Engineered Stress Relief Course (ESRC)

[1] TxDOT developed CAM and TOM-F specifications in different districts and later merged the two products. Today, most districts use TOM-F as a CAM interlayer. However, the CAM specification is still used by some districts.

Potential Benefits of CAM

Performance

Several DOTs have found success in using CAM interlayers in overlay systems. For example, TxDOT's Houston District first used a CAM interlayer on Interstate Highway 69 in 2014. The overlay system included a 1-inch CAM interlayer with a 1-inch thin overlay mixture-course (TOM-C) surface layer. The overlay was placed on an original continuously reinforced concrete pavement (CRCP) surface constructed in the 1960s. TxDOT repaired the existing concrete pavement to make it suitable for an asphalt overlay and avoid complete reconstruction.

TxDOT reports that the performance of the CAM overlay system has been noticeably better than that of conventional overlays. The Houston District used the CAM interlayer design because conventional 2-inch Type-D (3/4-inch maximum aggregate size) mixes had not performed well. Houston District engineers recall that 2-inch conventional overlays lasted 2 to 3 years before deteriorating rapidly with cracking, raveling, and aging. The expected design life of an overlay was supposed to be a minimum of 7 years, which left the roads in poor condition while TxDOT awaited funding to rehabilitate them (Kwater 2021).

Overall, the Houston District has been impressed by the performance of the CAM overlay system placed on IH-69. The overlay has been in service for 7 years, outlasting the conventional overlays used in the past. The hybrid of a CAM, now called TOM-F interlayer, and TOM-C surface course, with an appropriate bonding course when reflective cracking is a concern, is now the Houston District's go-to solution for rehabilitation.

Nevada DOT (NDOT) has significantly reduced reflective cracking on test sections using CAM interlayers. In 2015, NDOT placed engineered stress relief course (ESRC) interlayers alongside two control sections for comparison on US 95. The control sections included conventional dense-graded mixes and an interlayer that was not performance tested. Windshield surveys taken 1, 2, and 3 years after construction showed that performance-tested CAM interlayers are more effective in reducing the number and severity of reflective cracks than control mixes. A paper published in 2019 shows the windshield survey results of the pilot study on US 95 (Habbouche et al., 2019). Descriptions of the mixes used in the research project include:

- ESRC – Engineered stress relief course interlayer.
- SRC-T3 – Stress relief course interlayer is a typical type 3 fine-graded dense mix that is not performance tested for cracking and rutting resistance.
- OL-T2C – Conventional type 2 dense-graded overlay.

Each overlay was placed in the thicknesses illustrated in Figure 1 and topped with 0.75 inches of NDOT's standard practice surface open-graded friction course. The results from the windshield surveys are shown in Figure 2. The results show that the amount and severity of cracking are reduced when the ESRC is used.

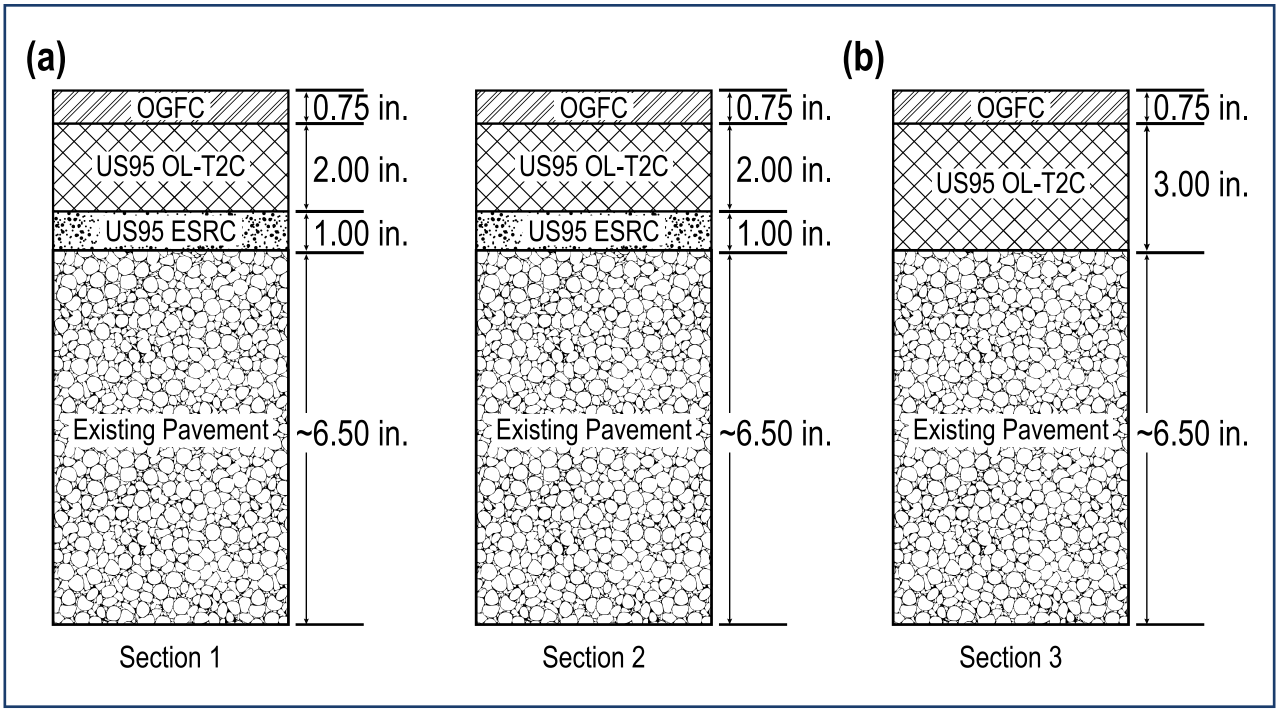

Figure 1. NDOT pilot ESRC interlayer with control sections placed on US 95. (Source: Habbouche et al. 2019)

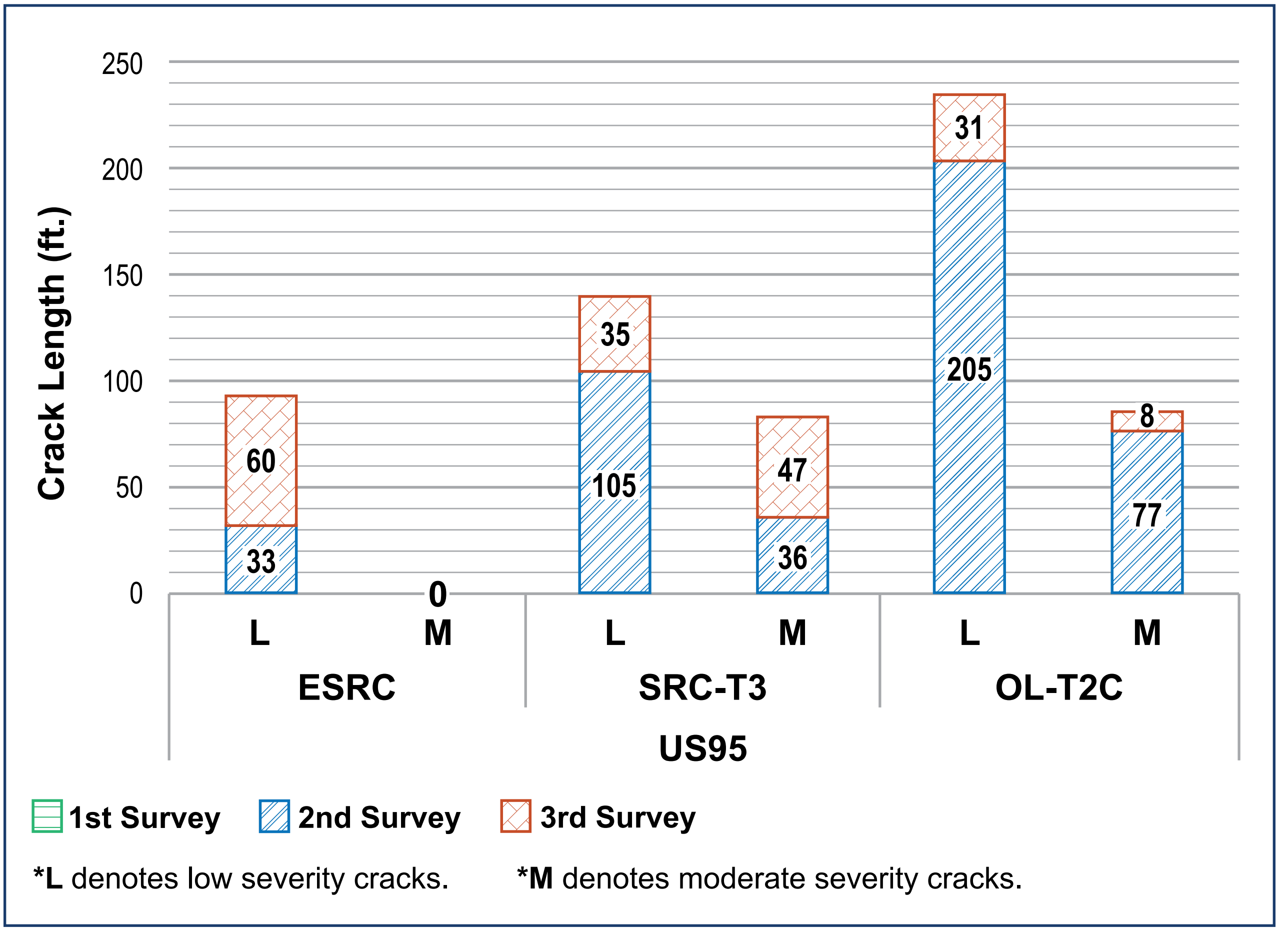

Figure 2. Results from the US 95 windshield survey. (Source: Habbouche et al. 2019)

Life Cycle Cost Analysis

NDOT also performed a life cycle cost analysis (LCCA) for the three test sections used in the study. The results are published in a 2019 report (Habbouche et al., 2019) and are summarized below. NDOT's Manual for Road Prioritization Category Life-cycles for Flexible Pavements was used to evaluate the LCCA for each strategy. The unit costs during construction were as follows:

- ESRC: $99 per ton.
- SRC-T3: Stress relief course interlayer, typical type 3 fine-graded dense mix not performance tested for cracking and rutting resistance: $87 per ton.
- OL-T2C: Conventional type 2 dense graded overlay: $67 per ton.

The distress data from the ESRC pilot projects were used to develop a reflective cracking model. According to the NDOT Manual for Road Prioritization Category Life-Cycles for Flexible Pavements, an asphalt overlay is applied after 12 years of new construction or rehabilitation. Based on this information, NDOT researchers anticipated that the ESRC section would have 6 additional years before seeing the same amount of reflective cracking as the SRC-T3 and T2C overlays. Therefore, NDOT researchers considered the following strategies:

- Strategy I-ESRC test section: 3-inch mill and fill with 1 inch of ESRC and 2 inches of T2C at years 12 and 30.
- Strategy II-SRC-T3 test section: 3-inch mill and fill with 1 inch of SRC-T3 and 2 inches of T2C at years 12 and 24.
- Strategy III-T2C test section: 3-inch mill and fill with T2C at years 12 and 24.

A 30-year period and a discount rate of 3 percent were selected for the analysis (Habbouche et al. 2019). The LCCA showed that using an ESRC interlayer led to 24 percent agency cost savings and 22 percent user cost savings compared to the other mixes. In summary, while the ESRC mixture had a higher initial cost, its agency and user life cycle costs per lane mile were lower, resulting in an average savings of 23 percent.

Reflective Cracking Mechanism

Reflective cracking is generally described as a crack in an asphalt overlay formed immediately above a joint or a crack in the underlying pavement. Three mechanisms contribute to reflective cracking (Bennert 2021):

- Mode 1: Excessive vertical bending at a joint or crack (classic tensile straining). Generates high tensile strain at the bottom of the HMA layer (Figure 3).
- Mode 2: Horizontal deflections due to environmental loading (temperature cycling). Most critical in colder temperatures with a significant cooling cycle (Figure 4).
- Mode 3: Shear force due to poor load transfer of underlying JPCP. Research has shown mode 3 is a crack accelerator rather than a crack initiator (Figure 5).

The intent of a CAM interlayer is to absorb some of these forces and mitigate the amount and severity of reflective cracking.

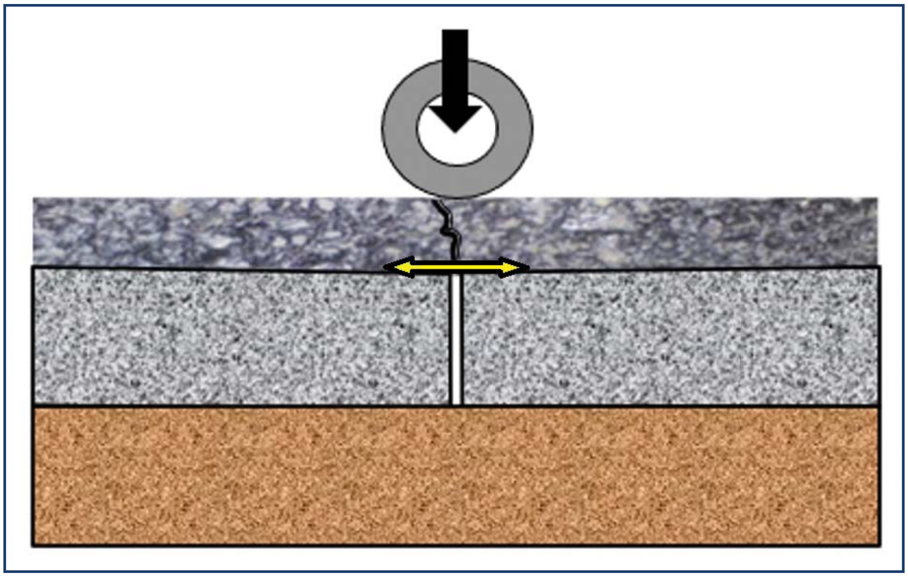

Figure 3. Mode 1: Vertical bending. (Source: Bennert 2021)

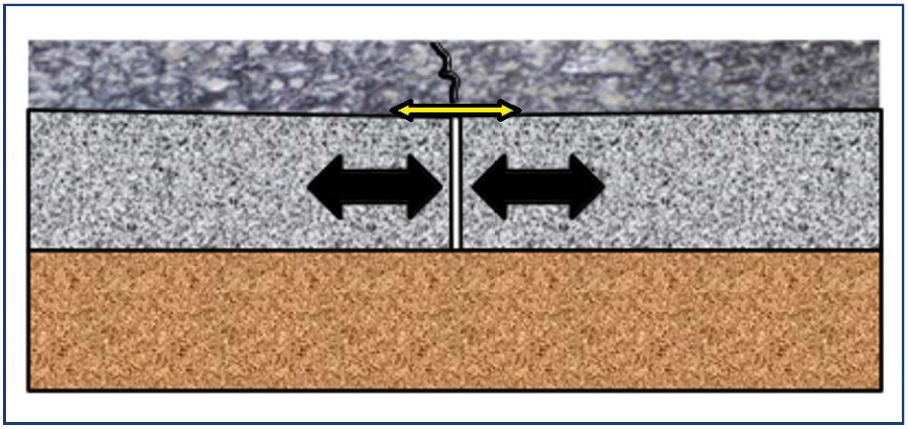

Figure 4. Mode 2: Horizontal deflections. (Source: Bennert 2021)

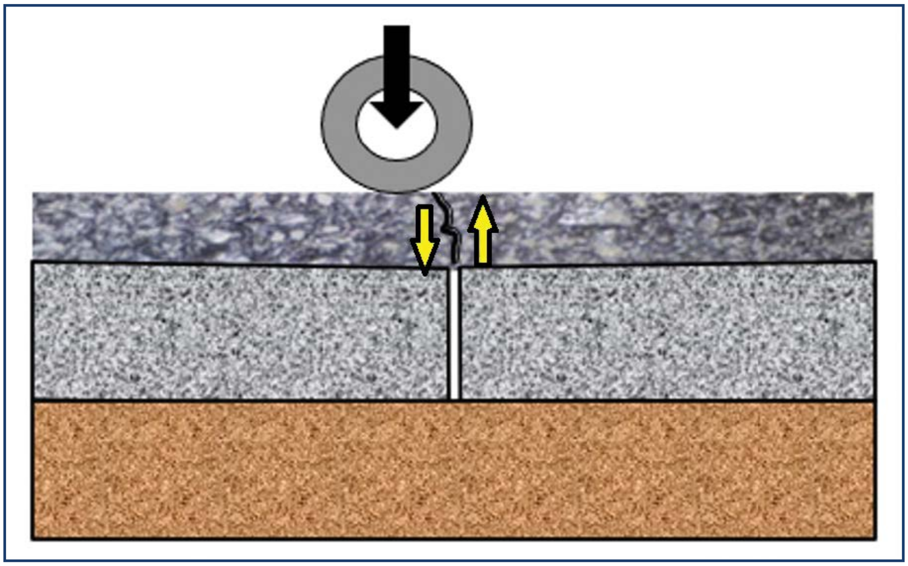

Figure 5. Mode 3: Poor load transfer of underlying pavement. (Source: Bennert 2021)

PROJECT DESIGN AND PLANNING

This section describes project design and development phase considerations for CAM overlay systems, such as establishing project selection criteria, pavement evaluation, cost benefits, existing pavement design and repair, and other project-specific considerations.

Project Selection Criteria

CAM is designed to be an interlayer. Therefore, it can be placed under the surface lift regardless of the thickness of the surface lift. Surface lift thickness should be considered during design and project selection. TxDOT originally started using CAM interlayers as a reflective cracking mitigation solution for JPCP rehabilitation. However, TxDOT has used these mixes successfully on concrete and asphalt surfaces where crack mitigation is desired.

Agencies should consider project needs and use appropriate project selection criteria and design processes. For example, TxDOT's Houston District has not developed exact thresholds to trigger the use of CAM. Generally, it is clear to TxDOT whether CAM will benefit the project based on the existing pavement condition.

Existing Pavement Repairs

Like other overlays, CAM interlayers should only be used on structurally adequate pavements (Arellano et al., 2014). Pavements with base problems should be avoided unless proper repairs are made. The following sections include some of NJDOT and TxDOT's repair practices.

Concrete Pavements

A common use of CAM interlayers is to mitigate cracking from JPCPs. NJDOT has successfully used binder-rich intermediate course (BRIC) as a CAM interlayer on concrete pavements to mitigate existing JPCP reflective cracking. NJDOT recommends sealing the existing concrete surface and using BRIC with a high-performing surface course, such as stone matrix asphalt (SMA) or a high-performance thin overlay (HPTO). NJDOT stresses the importance of repairing concrete pavement before placing BRIC (Blight 2021). Placing an overlay atop significant distresses may compromise the overlay's design life since the distresses will reflect through the overlay. Figures 6, 7, and 8 show examples of concrete repairs on NJDOT roadways made before placing overlays.

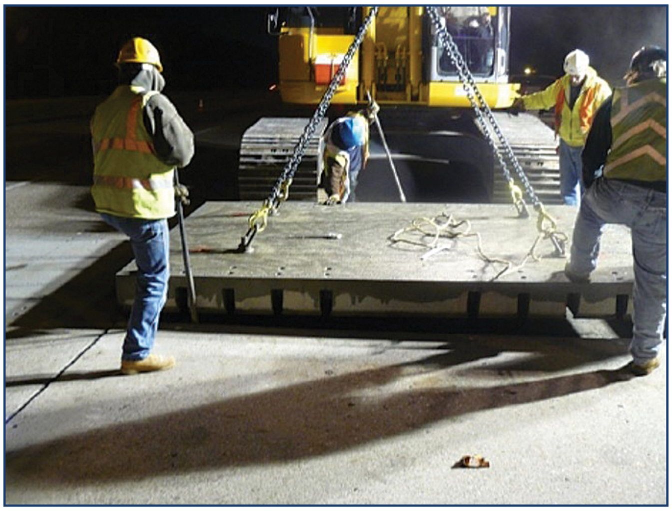

Figure 6. Full-depth slab repair using precast pavement. (Source: Blight 2021)

According to the TxDOT Pavement Manual (TxDOT 2021), JPCP distresses that need full-depth repair before rehabilitation include:

- Transverse cracks that extend through the depth of the slab.
- Shattered slabs.
- Corner breaks.

Figure 7. Spot repair. (Source: Blight 2021)

Figure 8. Slab stabilization using injection. (Source: Blight 2021)

Examples of shattered slabs and corner breaks are illustrated in Figure 9 and Figure 10, respectively (TxDOT 2016).

Figure 9. Shattered slabs need full-depth repair. (Source: TxDOT PMIS Rater's Manual 2016)

Figure 10. Example of corner breaks. (Source: TxDOT PMIS Rater's Manual 2016)

The TxDOT Houston District also uses CAM interlayers CRCP pavements. CRCP distresses that require full-depth repair (FDR) before rehabilitation are punchouts and deep spalling. Examples of punchouts and deep spalling are illustrated in Figures 11 and 12 (TxDOT 2021).

Figure 11. Punchouts require FDR. (Source: TxDOT Pavement Manual 2021)

Figure 12. Deep spalling requires FDR. (Source: TxDOT Pavement Manual 2021)

According to the TxDOT design manual, steps for full-depth repair include:

- Identify the repair limits.
- Saw-cut the perimeters.
- Remove the concrete slab.
- Remove the damaged base (if needed).
- Drill holes for longitudinal and transverse tie bars or dowel bars.
- Place and finish the concrete.
- Restore existing joints.

Asphalt Pavements

According to the TxDOT pavement manual, the existing substructure and asphalt should be investigated to ensure desired overlay performance, including CAM overlay systems. In addition to deflection measurements, ground penetrating radar combined with selective coring is one method to rapidly determine the depth and extent of delamination or stripping problems.

If the existing pavement has rut-susceptible layers within the top 4 inches of pavement, then rutting may continue since the layers fall within the zone of high shear and compression. Removing the rut-susceptible layers may increase the design life of the overlay. Also, certain surface materials, such as OGFC, should not be overlaid. Complete full-depth repairs of poor substructures before the overlay (TxDOT 2021).

Project Design

The CAM pavement design process is generally the same as other HMA overlays. Designers should consider whether conventional or thin overlay design procedures apply. TxDOT, NJDOT, and NDOT use the same structural design criteria for conventional overlays. NDOT performed falling weight deflectometer testing and coring on the ESRC test sections and adjacent control sections on US 95 (Figure 1). The agency found that the modulus results for the asphalt layers were comparable in all sections (Warrag 2020).

Thickness Criteria

Chapter 7 Flexible Pavement Rehabiliation of the TxDOT Pavement Manual (TxDOT 2021) describes CAM in Section 6.1 Structural Overlays. According to TxDOT, CAM products may be useful in reducing reflective cracking but should be covered with an adequate overlay thickness to provide resistance to rutting.

TxDOT originally developed CAM for urban environments as an overlay solution with a maximum overlay thickness of 2 inches (Scullion and Von-Holdt 2004). Similarly, NJDOT often cannot raise the elevation of roads due to environmental restrictions (Blight 2021). Therefore, TxDOT and NJDOT commonly use CAM interlayers with 1-inch to 2-inch surface lifts. The Houston District commonly uses a 1-inch TOM-F lift and a 1-inch TOM-C lift as a CAM overlay system. NJDOT has had success using 1 inch of BRIC under 2 inches of SMA surface course.

Surface Mixture Selection

TxDOT and NJDOT research highlights the importance of pairing CAM interlayers with a good surface mixture. TxDOT has found that the overlay system performs better when the surface mixture has some crack attenuating properties as opposed to stiff, dense-graded mixtures. In TxDOT's experiences, recycled materials such as recycled asphalt pavement (RAP) or recycled asphalt shingles (RAS) can contribute to stiffer mixes. Even a high-quality flexible crack attenuating layer cannot prevent stiff surface mixes from cracking. A phenomenon known as "crack jumping" can occur in an overlay system where the surface mix is much stiffer than the crack attenuating layer (Figure 13).

Figure 13. Crack jumping over a crack attenuating layer with a stiff surface mix. (Source: Bennert 2021)

Reflective cracking and crack jumping are less frequent when the surface mix has flexible crack attenuating properties (Bennert 2018, 2021). TxDOT commonly uses TOM-C as a surface lift over a CAM (TOM-F) interlayer. TOM-C is a coarser, more open-graded mixture with a lower minimum asphalt content requirement and good skid and rut-resistant properties. TOM-C mixes are tested for reflective crack resistance using the overlay tester. However, the mix design specification requires only 300 cycles to failure, compared to CAM's 750-cycle requirement.

NJDOT commonly uses a BRIC and SMA hybrid overlay system. Research at Rutgers University shows BRIC reduces reflective cracking from horizontal deflections, and SMA reduces reflective cracking from the vertical deflections of underlying joints or cracks (Bennert 2021). Bennert (2018) plotted the performance data from six overlays to further prove the importance of BRIC's surface mix (Figure 14). Combinations using the following four material types were evaluated:

- BRIC
- 9.5mm or 12.5mm HMA – dense-graded asphalt
- 9.5 mm or 12.5 mm SMA
- 12.5 mm M64 – standard dense graded asphalt designed at 75 gyrations using performance grading (PG) 64-22 neat binder (typical surface course for low to moderate traffic in NJ) (Bennert, 2021).

The data are shown using NJDOT's surface distress index (SDI), a pavement condition index ranging from 0 to 5 calculated from ride quality and surface distresses. NJDOT has a rehabilitation trigger for pavements at or below an SDI of 2.4. Pavements with an SDI above 2.4 are considered fair to good condition.

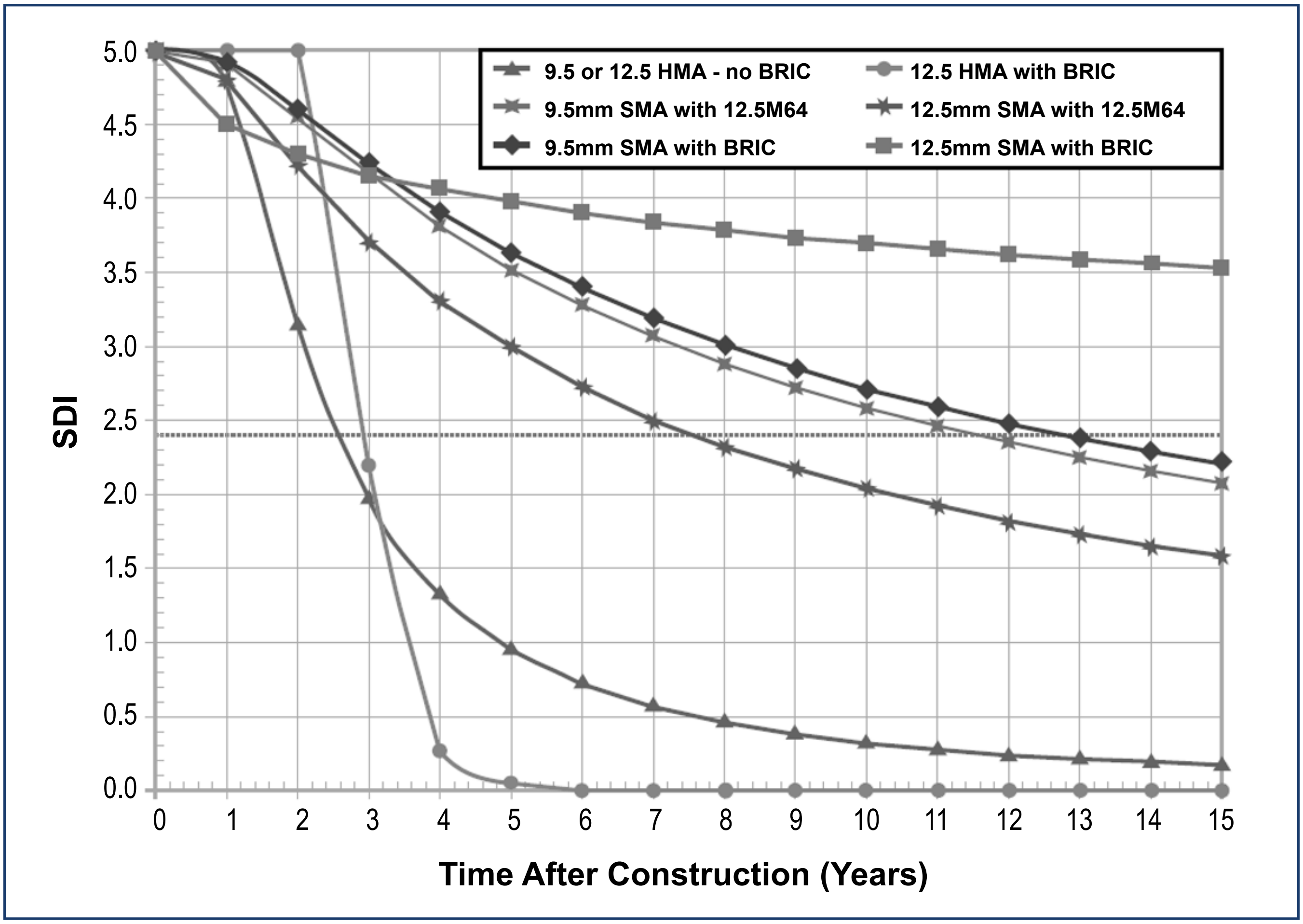

Figure 14. Comparison of different overlay systems at NJDOT. (Source: Bennert 2018)

Bennert (2018) concluded the following using the data in Figure 14:

- The SDI of the 12.5mm dense graded with BRIC overlay dropped significantly after just 3 years. There was no noticeable improvement to SDI using BRIC under the dense-graded mix.
- The highest performing overlays, according to SDI, were the SMA-BRIC hybrid systems. The SDI remained at or above the 2.4 rehabilitation trigger for 13 years using the 9.5 mm SMA and remained above 3.5 for at least 15 years.
- Based on this data, the 12.5mm M64[2] mixes appear to have some crack attenuating properties.

[2] M64 is standard dense-graded asphalt designed at 75 gyrations using PG 64-22 neat binder (typical surface course for low to moderate traffic in NJ) (Bennert, 2021).

MIXTURES AND MATERIALS

The following section includes information on mixtures and material selection.

Aggregates

CAM products are generally placed in 1-inch lifts. TxDOT specifies a magnesium sulfate ($MgSO_4$) soundness loss of 20 or less for critical sections and 25 or less for non-critical sections (TxDOT 2014, Wilson 2015). In addition, TxDOT also requires the aggregate to meet surface aggregate classification (SAC) criteria. Aggregate can be classified as SAC A, B, or C. Frictional and durability indicators such as polish value, soundness, acid insolubility, and micro deval tests are used to classify the aggregates. In TxDOT's experience, SAC A has the highest frictional and durability properties. Table 2 shows some of TxDOT's aggregate quality requirements.

Table 2. Coarse Aggregate Quality Crtieria - TxDOT Item 347 for TOM.[3]

Property	Aggregate Fraction	Test Method	Criteria
Surface aggregate classification	Coarse	Tex-499-A (AQMP)	A[1]
Deleterious material, %, max	Coarse	Tex-217-F, Part I	1.5
Decantation, %, max	Coarse	Tex-217-F, Part II	1.5
Micro-Deval abrasion, %	Coarse	Tex-461-A	Note 2
Los Angeles abrasion, %, max	Coarse	Tex-410-A	30
Magnesium sulfate soundness, 5 cycles, %, max	Coarse	Tex-411-A	20
Crushed face count[3], %, min	Coarse	Tex-460-A, Part I	95
Flat and elongated particles @ 5:1, %, max	Coarse	Tex-280-F	10
Linear shrinkage, %, max	Fine	Tex-107-E	3
Sand equivalent, %, min	Combined[4]	Tex-203-F	45

1. Surface aggregate classification of "A" is specified unless otherwise shown on the plans.
2. Used to estimate the magnesium sulfate soundness loss in accordance with Section 347.2.1.1.2., "Micro-Deval Abrasion."
3. Only applies to crushed gravel.
4. Aggregates, without mineral filler or additives, combined as used in the job-mix formula.

The specific job mix formula requirements for CAM (TxDOT), TOM-F (TxDOT), BRIC (NJDOT), and ESRC (NDOT) are shown in Figure 15. TOM-F and CAM gradations are nearly identical. Today, most TxDOT districts use TOM-F specifications for CAM interlayers, although some districts still prefer the CAM specification. BRIC and ESRC gradation bands are finer than CAM and TOM-F, with BRIC having the finest upper limit.

Asphalt Binders

TxDOT, NJDOT, and NDOT all specify polymer-modified binders for CAM. Polymer-modified binders are critical for achieving the performance testing criteria for CAM products (TxDOT 2014, TxDOT 2017, NJDOT 2018, Warrag and Hajj 2020). Binder grades are climate-specific and vary by agency. However, they all require

[3] These criteria are not Federal requirements.

performance grading, and some are required to meet additional criteria such as TxDOT's use of elastic recovery. The following sections describe TxDOT, NJDOT, and NDOT asphalt binder requirements for CAM products.

TxDOT

TxDOT generally follows typical classification for PG binders. In addition to the standard testing requirements, TxDOT also requires elastic recovery testing for binders in CAM products, according to ASTM D 6084 (TxDOT 2014).[4] TxDOT requires a high-temperature grade of PG 76 or 70, and the low-temperature grade varies by District. In 2019, TxDOT reported partially replacing elastic recovery testing with the percent recovery of multiple stress creep recovery testing (Barborak 2019).

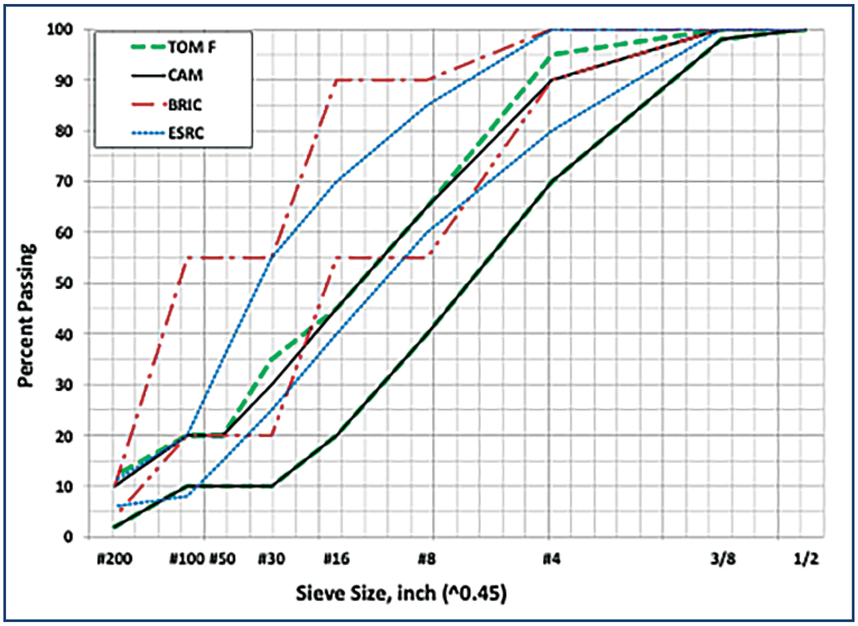

Figure 15. Typical Gradations – TOM-F, CAM, BRIC, ESRC. (Source: FHWA)

NJDOT

NJDOT specifications require a polymer-modified asphalt binder specially formulated to meet the specification's mix performance criteria. Specific binder grades are not mentioned in the specifications. NJDOT requires a certificate of analysis showing the PG continuous grading (AASHTO R 29)[5] for the asphalt binder used in the mix design. NJDOT also samples the binder and completes quality assurance checks and polymer content throughout the paving process.

NDOT

NDOT specifications require PG 64-28NV or PG 76-22NV binder in CAM products. This binder must meet hybrid requirements, including typical AASHTO grading and Nevada test methods. Additional Nevada test methods include Ductility (Nevada T746), Sieve (Nevada T730), and Toughness and Tenacity (PG 64-22NV only, Nevada T745). NDOT requires that the PG 76-22NV binder certificate of analysis include the polymer content. NDOT may elect to test for polymer content according to AASHTO T 302 Standard Test Method for Polymer-Modified Emulsified Asphalt Residue and Asphalt Binders.[6]

Recycled Materials

Recycled asphalt pavement and recycled asphalt shingles are not permitted by TxDOT, NJDOT, or NDOT in CAM products.

[4] ASTM D 6084 is a TxDOT requirement. Its use is not a Federal requirement.

[5] AASHTO R 29 is a TxDOT requirement. Its use is not a Federal requirement.

[6] AASHTO T 302 is an NDOT requirement. Its use is not a Federal requirement.

Mixture Design and Performance Testing

Generally, mixture design methodology is agency dependent. Modified mixture design criteria are generally based on observed field performance and research results. Many States use AASHTO M 323 for 9.5- and 4.75-mm mixtures, but its use is not a Federal requirement.

Table 3 summarizes the laboratory mix design property specification requirements for CAM, TOM-F, BRIC, and ESRC for comparison. The performance tests used to evaluate the mixes are summarized in the following sections.

Table 3. Mix Design Properties.

Mix Property	CAM (TxDOT SS3000)	TOM-F (TxDOT 347)	BRIC (NJDOT 407)	ESRC (NJDOT 3775)
Binder Content (total weight of mix), min. %	7.0	6.5	7.4	7.0
Design VMA, min. %	17.0	16.5	18.0	16
Design Gyrations	50	50	50	50
Lab-molded density, %	98.0	97.5	97.5	N/A
Tensile strength ratio, %	N/A	N/A	85	N/A
Tensile strength, PSI	85-200	85-200	N/A	N/A
Design Air Voids, %	N/A	N/A	N/A	0.5-2.5
Dust/asphalt	1.4 max.	N/A	0.6-1.2	0.6-1.4
Draindown, %	N/A	0.20 max.	0.10 max.	N/A
Hveem Stabilometer, min.	N/A	N/A	N/A	18
Hamburg Wheel Test, min. passes at 12.5 mm rut depth[7]	PG 64 or lower: 10,000 PG 70: 15,000 PG 76 or higher: 20,000	PG 70: 15,000 PG 76: 20,000	N/A	N/A
Overlay Tester, min. cycles	750[8]	varies[9]	700[10]	PG 64-28NV: 2,000[11] PG 76-22NV: 1,750[7]
Asphalt Pavement Analyzer (APA), min passes at 6 mm rut depth[12]	N/A	N/A	8,000	N/A
Flexural Beam Fatigue, min. cycles[13]	N/A	N/A	N/A	PG 64-28NV: 10,000 PG 76-22NV: 7,000
Repeated Load Triaxial test	N/A	N/A	N/A	No Criteria

[7] Applied load of 158±5 lb. at 52±2 passes per second in water bath at 122±2˚F

[8] Tested at 77±1˚F at 5±1% air voids with 0.025 inch displacement.

[9] Tested at 77±1˚F at 7±1% air voids with 0.025 inch displacement. Item 347 describes TOM-F and TOM-C. TOM-F can be used as an interlayer or surface layer. The default threshold in the Item 347 specification is 300. However, districts often modify this to a higher value when used as a CAM interlayer.

[10] Tested at 77˚F at 3.5±0.5% air voids with 0.025 inch displacement.

[11] Tested at 50˚F at 7±0.5% air voids with 0.018 inch displacement.

[12] Tested at 149˚F with 100 psi hose pressure and 100 lbs. load.

[13] Tested at 2000 micro-strain, 20 Hz, 3±1% air voids at 59˚F.

Performance Test Descriptions

TxDOT, NJDOT, and NDOT all use performance testing to evaluate a CAM product's resistance to cracking and rutting. All three DOTs use the Overlay Tester to evaluate mixes for cracking resistance. However, the procedures and evaluation criteria vary, as shown in Table 3. In addition to the Overlay Tester, NDOT uses the flexural beam fatigue test to evaluate resistance to fatigue cracking. Each DOT uses a different test procedure with unique equipment to evaluate rut resistance. TxDOT uses the Hamburg Wheel Tracking Test (HWTT), NJDOT uses the Asphalt Pavement Analyzer (APA), and NDOT uses the Repeated Load Triaxial Test.

Rut Resistance

Hamburg Wheel Tracking Test

TxDOT uses the HWTT (Figure 16) to evaluate rut resistance according to the procedures outlined in Tex-242. This test method determines the premature failure susceptibility of asphalt mixtures due to weak aggregate structure, inadequate binder stiffness, moisture damage, and other factors, including inadequate adhesion between the asphalt binder and aggregate (TxDOT 2019). The HWTT apparatus is an electronically powered temperature-controlled device with an 8-inch diameter 1.85-inch wide steel wheel that makes repeated passes over the surface of 6-inch gyratory or core specimens. One test set uses two specimens positioned in a single mold. The wheel applies a load of 158±5 pounds and makes 52 ±2 passes per minute at a speed of approximately 1-foot per second. TxDOT performs the test in a water bath that can run the test over a range of 77 degrees Fahrenheit to 158 degrees Fahrenheit.

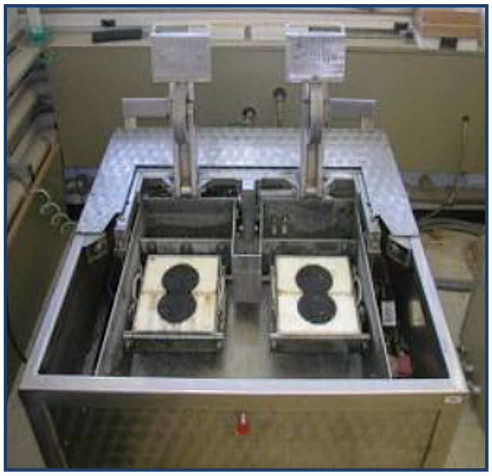

Figure 16. HWTT apparatus and specimens. (Source: TxDOT)

Asphalt Pavement Analyzer

NJDOT uses the APA (Figure 17) for rut resistance testing. The APA is another wheel tracking device that works similarly to the HWTT, but with a different loading mechanism; the APA uses a pressurized rubber tube between the sample surface and wheel. Six specimens are tested using an APA according to AASHTO T 340[14] at 64 degrees C (147.2 degrees F) using a 100 psi hose pressure and 100-pound wheel load. NJDOT tests specimens under dry conditions.

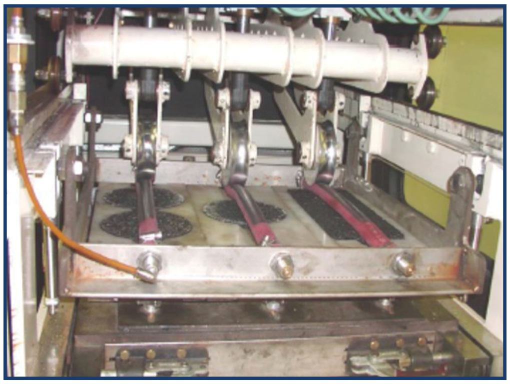

Figure 17. Asphalt Pavement Analyzer. (Source: Dr. Tom Bennert)

Repeated Load Triaxial Test

NDOT evaluates resistance to rutting using the Repeated Load Triaxial Test with specimens 4 inches in diameter and 6 inches tall. The specimens are placed in a triaxial chamber and subjected to a repeated haversine deviator stress of 70 psi with a 0.1 second loading time and a 0.9 second rest period. The test is conducted under a 10 psi confinement pressure. The test results include a flow number and the cumulative, permanent strain curve, which is used to characterize the rutting behavior of the mixtures (Warrag 2020).

[14] Use of AASHTO standard is not a Federal requirement.

Crack Resistance

Overlay Test or Texas Overlay Tester

The Overlay Test (Figure 18) is an electro-hydraulic system that applies repeated direct tension loads to specimens. The apparatus features two blocks – one is fixed, and the other slides horizontally. The sliding block applies a tension force in a cyclic triangular waveform to a constant maximum displacement of 0.025 inches (NDOT uses an asphalt mixture performance test machine with a displacement of 0.018 inches). The time for each loading load cycle is 10 seconds. Sample preparation for the Overlay Test includes saw cutting 6-inch gyratory specimens (or cores) to extract only the innermost middle portion (Figure 19). This specimen gets epoxied to the fixed and sliding blocks. Placing 10-pound weights on the blocks (Figure 20) helps bonding while the epoxy cures, which generally takes 8 hours (TxDOT 2017).

The testing conditions and criteria used by each DOT are unique (Table 3). NDOT found that all of its mixes far exceeded the Overlay Test criteria when tested according to the parameters in Tex 248 used by TxDOT. Nevada and Texas climates, binder, and aggregate sources are different. Even within Nevada, the weather changes significantly in different regions. Therefore, NDOT developed test parameters and criteria to reflect climate and mixtures.

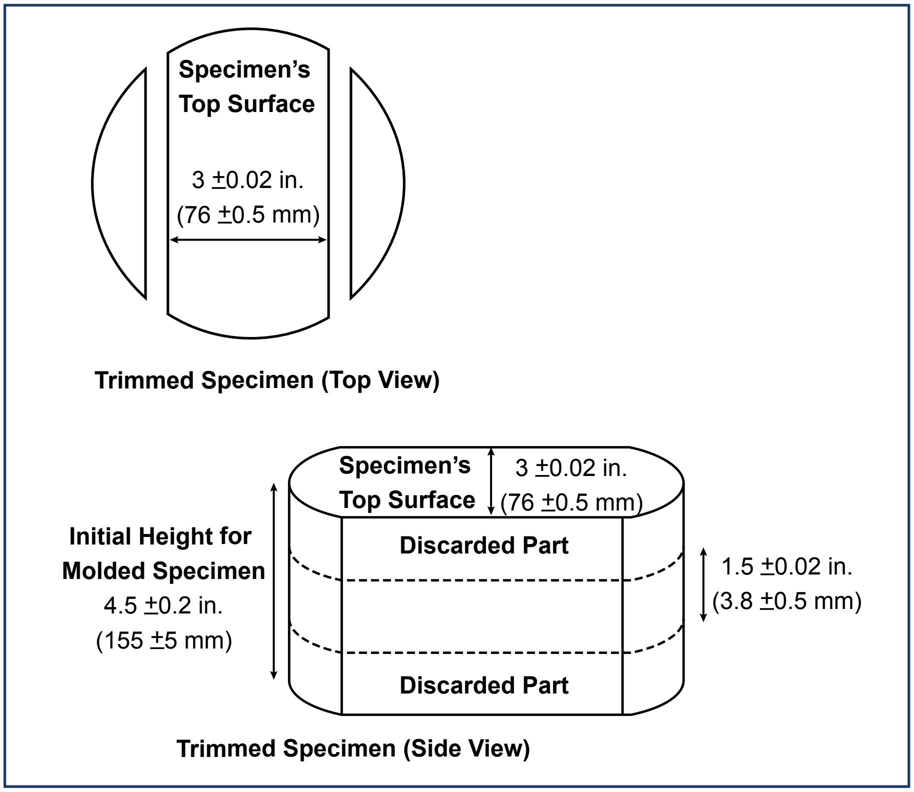

Figure 19. Using the middle portion of a 6-inch gyratory sample or core. (Source: TxDOT 2017)

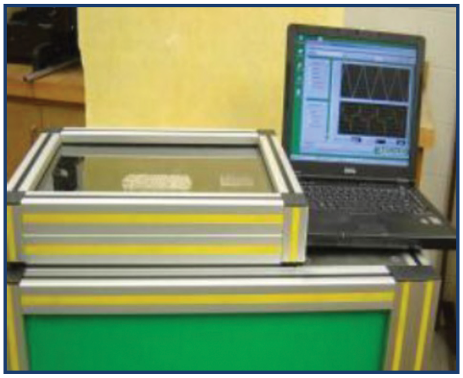

Figure18. Overlay Test Device. (Source: TxDOT 2014)

Figure 20. Weighted specimens after being epoxied to blocks. (Source: TxDOT 2017)

Flexural Beam Fatigue

NDOT also uses flexural beam fatigue (AASHTO T 321) to evaluate resistance to fatigue cracking. The concept of a fatigue life centers around the idea that most materials gradually deteriorate under repeated loads much smaller than the material's ultimate strength. The Flexural Fatigue Test investigates fatigue related to HMA construction materials (Hajj 2017). Flexural beam fatigue samples are 15 by 2 by 2.5 inches (cut from a compacted specimen) and are placed in a four-point loading machine (Figure 21). The sample is subject to a 4-point bending haversine load of 10 Hz frequency. According to the ESRC criteria, samples should withstand a minimum of 7,000 loading cycles before failure.

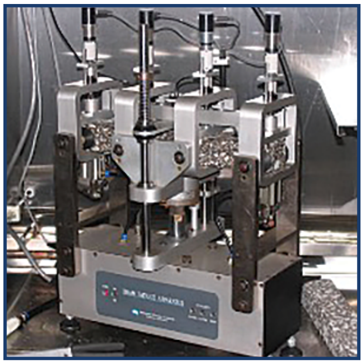

Figure 21. Flexural beam fatigue sample and apparatus. (Source: Pavement Interactive 2021)

CONSTRUCTION SPECIFICATIONS AND PRACTICES

The construction practices followed for thin overlay asphalt applications apply to CAM interlayers. Construction considerations are included in the following sections.

Materials

TxDOT, NJDOT, and NDOT agree it is essential to specify high-quality aggregates and asphalt binders in the specification materials section. The aggregate qualities and properties used in CAM products are discussed in this document's Mixtures and Materials section.

A high-quality tack coat, either emulsion or liquid asphalt, is critical to overlay long-term performance, including CAM. Bonding is the number one issue in (thin) overlay construction in Texas (TxDOT 2014). According to an FHWA Technical Brief published in 2016, a 60 to 75 percent loss of life can be expected if a pavement displayed no bonding within its layers. This report states that even a bond loss of just 10 percent could reduce fatigue life by 50 percent. If the overlay system does not achieve adequate bond strength, its performance is notably reduced. Therefore, the bonding mechanism under the CAM interlayer is critical.

According to TxDOT specifications, a bonding course (SS3084) or an underseal course (SS3085) can be used as improved bonding and sealing courses (TxDOT 2019). These courses use a tracking-resistant asphalt interlayer or spray applied underseal membrane. TxDOT guides Districts on selecting bonding layers in the Interlayer Material Guide (TxDOT 2019). As the name indicates, the bonding course's intended use improves bonding compared to conventional tack products. The significant difference between the bonding and underseal courses is the application of an aggregate cover over the underseal. The underseal provides additional sealing of the underlying surface if needed. Some overlap of bonding and sealing benefits exist between these products, dependent on the application equipment, temperatures, and rates.

Because bonding is critical for successful overlay construction, TxDOT pays for tack, bonding course, and underseal course as individual pay items. TxDOT quality assurance procedures for bonding layers include requiring a test strip and performing informational Shear Bond Strength Tests (Figure 22) according to Tex-249. This test determines the shear strength between two bonded layers, typically 6-inch field cores, using a device with one fixed sleeve and one sliding sleeve. The sleeves are placed on either side of the bonding layer, and an applied vertical force on the sliding sleeve evaluates the shear strength of the bond. Bond strength can also be

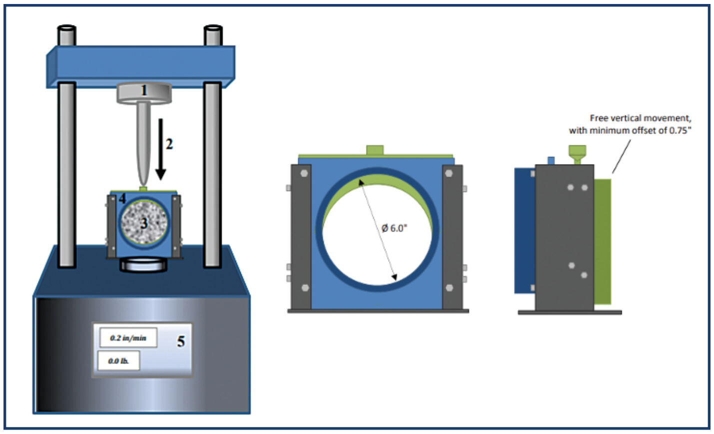

Figure 22. Shear Bond Strength Test. (Source: TxDOT 2019)

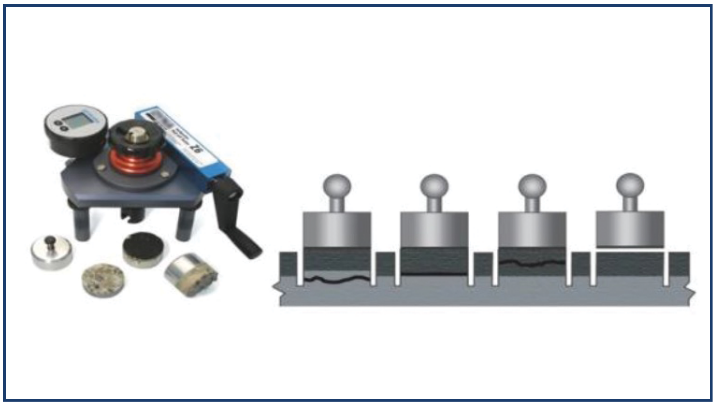

Figure 23. Pull-Off Bond Strength Tester. (Source: TxDOT 2014)

tested in the field using a pull-off bond strength tester (Figure 23). The pull-off tester effectively determines field bonding (TxDOT 2014).

Production, Storage, and Transportation

The following sections summarize some CAM production, storage, and transportation considerations.

Mixture Production

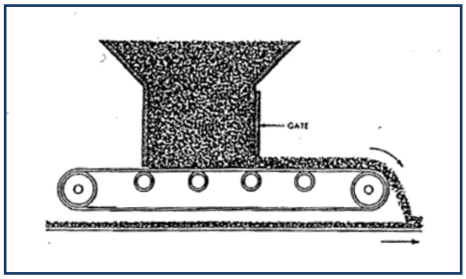

Figure 24. Example of feeder bin gate opening. (Source: AI 2001)

Aggregate feeder calibrations at the asphalt plant are critical to ensure consistent asphalt (Roberts et al., 1996). Ensuring proper aggregate plant calibrations is not a quality control practice specific to CAM. Still, there are some differences to consider when using fine asphalt mixtures like CAM. According to the Hot Mix Asphalt Materials Mixture Design and Construction (Roberts et al. 1996), gates can be opened to various heights to change the rate of flow of the material. Feeder bin gate openings (Figure 24) for fine aggregate piles may differ from those used on coarser aggregate piles since the desired opening is based on the aggregate's size. Therefore, feeder calibrations should be considered when switching production from larger nominal maximum aggregate size (NMAS) mixtures to small NMAS mixtures like CAM.

Fine aggregate stockpiles usually contain more moisture than coarse aggregate piles (Newcomb 2009). Increasing the frequency of stockpile moisture content checks for CAM and other fine-graded thin overlay products may be beneficial since moistures can play a significant role in plant consistency and production (AI 2001). According to the Asphalt Institute's Construction of Quality Asphalt Pavements MS-22, for drum mix asphalt plants, the aggregate is weighed on the belt before drying. Since the undried material may contain an appreciable amount of moisture that can influence the aggregate's weight, an accurate measurement of the aggregate moisture is important. The moisture measurement is used to adjust the automatic metering system of asphalt. The proper amount of asphalt is added based on the weight of the aggregate minus the measured moisture content. The MS-22 suggests checking moistures twice daily during production and more if there is variation.[15]

[15] The use of MS-22 is not a Federal requirement.

Minimizing moisture content in the stockpiles can also reduce production costs (Newcomb 2009). According to National Asphalt Pavement Association's Thin Asphalt Overlays for Pavement Preservation publication, plants generally run slower for fine-graded or small NMAS mixtures compared to larger NMAS mixtures. One reason is that the higher moisture contents require a longer drying time. There is about a 10 percent savings in fuel with every one percent decrease in moisture content (Newcomb 2009). Therefore, good stockpiling practices such as paving underneath the stockpile, sloping the pad to drain water, and covering the stockpiles can reduce production costs (Newcomb 2009).

Storage and Transportation

Long storage time in silos should be avoided as it may affect the quality of the mixture. NJDOT and TxDOT use draindown thresholds in its mix design criteria to determine the amount of draindown in an asphalt sample when subjected to temperatures comparable to those encountered during production, storage, transport, and placement (TxDOT 2016).

The material should be transported to the construction site using trucks with clean beds, preferably fitted with mechanisms, such as tarps and insulated beds, to reduce temperature loss in the mixture. Using solvents to clean the truck beds should not be permitted as it can contaminate the mixture, resulting in a poor-quality material.

The TxDOT Houston District recommends using warm-mix asphalt (WMA) for TOM mixes (interlayer and surface courses) if the plant to job haul distance exceeds 40 miles. The WMA is required as a compaction aid only, and no reduction in temperatures is permitted.

Surface Preparation

Surface preparation includes spot repairs, milling, crack sealing, or other repairs dictated by existing pavement evaluation.

Overlays, including CAM systems, should not be placed on structurally compromised pavements. Pavement repairs may be used to prepare pavements for overlay, as discussed in the Project Design and Planning section of this document.

Placement and Compaction

NJDOT specifications enforce strict weather limitations and state that BRIC should not be placed if the National Weather Service forecasts a 40 percent or greater chance of rain during the scheduled placement. NJDOT specifications require the roadway surface temperature to be 50 degrees Fahrenheit or above.

TxDOT requires a minimum air temperature above 70 degrees Fahrenheit for TOM interlayer and surface mixes (TxDOT 2021).

CAM may be placed using a conventional paver or spray paver (also called an ultra-thin paver). TxDOT and NJDOT both require the use of a material transfer vehicle (MTV) for CAM (Figure 25). An MTV may reduce the asphalt's physical and thermal segregation, leading to more uniform compaction of the mat. An MTV's surcharge capacity helps keep paving operations continuous to optimize smoothness.

A paver-mounted thermal profiler (PMTP) may be specified to monitor thermal segregation and help correct the paving practices that cause segregation. TxDOT's Houston District requires a PMTP when using TOM-F interlayers to demonstrate the mixture is being placed with minimal segregation (TxDOT 2021).

A test strip is an opportunity for DOT personnel to understand the behavior of the mixture during production, placement, and compaction in the field. It also provides an opportunity to establish optimal rolling patterns. NJDOT requires an approved test strip before full BRIC production can commence (NJDOT 2017).

Figure 25. Use of MTV with tandem breakdown rollers. (Source: Tom Scullion, TTI)

Compaction may be performed with standard double drum vibratory rollers. However, if the breakdown of aggregate or bleeding of asphalt binder is observed, rolling operations may be required to be performed in static mode only. TxDOT and NJDOT do not permit pneumatic rollers as the wheels may pick up the CAM and BRIC mixture.

TxDOT recommends the use of tandem breakdown rollers for thin lifts like CAM. A general rule of thumb for successful practice is to keep the tandem breakdown rollers within 100 feet of the paver (Kwater 2021). CAM products have higher AC and use polymer-modified asphalts. Therefore, the mixes tend to be sticky, and adding release agents to the water systems on the rollers is recommended (TxDOT 2015).

TxDOT (Tex-246) recommends using the water flow test (Figure 26) when establishing rolling patterns for TOM-F interlayers. The Houston District's construction notes state that the water flow measurement should be used to establish rolling patterns. The water flow is measured using a cylindrical field permeameter which channels water onto the pavement surface. The mixes are evaluated to confirm minimum flow times are met to ensure compaction.

Figure 26. Water flow test. (Source: TxDOT 2015)

Quality Acceptance and Quality Control Requirements

Standard acceptance and quality control requirements should be considered for CAM mixes. For more information, the NJDOT BRIC specification can be found in Section 407 in the Updated Standard Specification for Road and Bridge Construction updated in 2018. TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges Item 347 (2014) includes TOM-C and TOM-F specifications. CAM specifications can be found in TxDOT SS3000. NDOT ESRC specifications can be found as special provisions under the 401 specification.

Tools for Quality Construction

Intelligent Construction Technologies

Intelligent construction technologies are a combination of modern science and innovative construction technologies. Examples include intelligent compaction and PMTP. Using intelligent compaction and PMTP allows contractors to measure real-time temperature and compaction operations during paving, track progress visually, record measured data and machine settings digitally, and report everything from the field using technically advanced equipment.

Balanced Paving Applications

Successful practices ensure proper trucking and compaction efforts are available to balance production and paving operations. Thin-lift paver speeds used for CAM lifts may be faster compared to conventional, thicker asphalt lifts. Also, compaction efforts may differ from conventional thicker lifts due to shorter compaction windows. Several free tools are available to help balance paving operations.

SUMMARY

This how-to document described CAM interlayer projects used by TxDOT, NJDOT, and NDOT. These DOTs use similar fine-graded, high asphalt content mixes with polymer-modified binders that are performance tested for cracking and rutting resistance. The types of performance tests vary, and the test criteria are modified for different climates and mixes.

CAM interlayers should be paired with a suitable surface mix and constructed using agency best practices for thin lift applications. Proper bonding between lifts and adequate compaction to ensure impermeability is important. TxDOT, NJDOT, and NDOT have found that a successfully placed CAM interlayer can significantly delay reflective cracking and increase the surface life of pavements.

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TOPS
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