TOPS

Targeted Overlay Pavement Solutions

Highly Modified Asphalt Florida Case Study

December 2021

U.S. Department of Transportation
Federal Highway Administration

Every Day Counts
Innovation for a Nation on the Move

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15. Supplementary Notes This is one of five case studies highlighting FHWA's Every Day Counts initiative known as Targeted Overlay Pavement Solutions. TOPS integrate innovative overlay procedures into practices to improve performance, lessen traffic impacts, and reduce the cost of pavement ownership. FHWA Project Manager: Tim Aschenbrener; Principal Investigator: Shreenath Rao		
16. Abstract Highly modified asphalt (HiMA) is an asphalt mixture containing asphalt binder that is typically modified with 7 to 8 percent polymer. Styrene-butadiene-styrene is most commonly used and is more than twice what is typically used in conventional polymer-modified binders. By increasing the polymer content, the structure changes to a swollen polymer with a dispersed asphalt phase, making the resulting binder behave more like rubber. HiMA is used for a range of applications, including full-depth to thin asphalt overlays under different traffic conditions. The Florida Department of Transportation (FDOT) has increasingly used HiMA to address severe rutting, fatigue, reflective cracking, and raveling. This report is a case study of FDOT's experience and includes background, specifications, implementation, design, planning, construction, and performance.		
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CONTENTS

- Overview 5
- Background 7
- Research Activities 9
- Implementation........ 11
- Construction........ 13
- Performance and Evaluation 15
- Conclusions and Recommendations 17
- Acronyms 18
- References 19

LIST OF FIGURES

- Figure 1. Effect of increasing styrene-butadiene-styrene polymer content on binder/polymer morphology (Source: Kraton Polymers)........ 7
- Figure 2. HiMA performance on Oklahoma's I-40 (Source: Gary Fitts)........ 8
- Figure 3. FDOT's HVS and APT tracks and experimental pavement structures (Source: FDOT) 9
- Figure 4. Structural designs for (a) rutting and (b) fatigue cracking test sections (Source: FDOT) 10
- Figure 5. Average rut depth progression (Source: FDOT)........ 10
- Figure 6. Rutting performance before and after placement of HiMA friction course (Source: FDOT) 12
- Figure 7. Approved HiMA suppliers for FDOT projects. (Source: FDOT)........ 13
- Figure 8. US-90 Midway project after treatment (Source: Gary Fitts). 15
- Figure 9. Performance of experimental sections a) reflective cracking, b) rutting, and c) smoothness (Source: FDOT) 16-17

LIST OF TABLES

- Table 1. FDOT rolling thin film oven test residue binder requirements........ 12

HIGHLY MODIFIED ASPHALT (HIMA)

This is one of five case studies highlighting FHWA's Every Day Counts initiative known as Targeted Overlay Pavement Solutions (TOPS). The purpose of TOPS is to integrate innovative overlay procedures into practices to improve performance, lessen traffic impacts, and reduce the cost of pavement ownership.

Overview

Highly modified asphalt (HiMA) mixtures contain asphalt binder that is typically modified with 7 to 8 percent polymer, most commonly styrene-butadiene-styrene (SBS). This amount of polymer is more than twice what is used in conventional polymer modified binders—approximately 3 percent by weight of the binder. According to Florida Department of Transportation (FDOT) research (Habbouche et al. 2019), the binder-polymer structure of conventional modified binders consists of asphalt binder with a dispersed swollen polymer phase that improves binder properties. By increasing the polymer content, the researchers found that the structure changes to a swollen polymer with a dispersed asphalt phase. This makes the resulting binder behave more like rubber and enhances cracking resistance and rutting performance.

FDOT initially adopted the use of HiMA binder as a mechanism to address severe rutting observed in high-stress locations subject to heavy axle loads and slow-moving traffic, such as truck weigh stations, agricultural inspection stations, and high-volume intersections and interchanges. FDOT's idea of using a high-polymer content binder to improve rutting resistance was prompted by results obtained from experimental test sections constructed at the National Center for Asphalt Technology Test Track in Auburn, Alabama.

Research

FDOT confirmed through its Accelerated Pavement Testing program that HiMA mixtures reduce rutting and improve cracking performance (Greene et al. 2014). The agency constructed its first implementation projects in 2015, and based on what FDOT considered successful outcomes, modified State specifications in July 2017 to replace PG 82-22 binder with high-polymer modified binder. Since then, FDOT has placed more than 500,000 tons of HiMA mixtures on at least 40 projects across Florida. In addition, FDOT has implemented HiMA for other purposes, such as mitigating reflective cracking from construction joints in overlaid portland cement concrete pavements and reducing raveling in open-graded friction courses. According to FDOT research, HiMA mixtures increase structural contribution, potentially allowing for a reduction in pavement thickness without sacrificing performance.

Construction Considerations

Based on FDOT's experience, producing and handling HiMA binders involves the following special considerations:

- Controlling the storage temperature and limiting the storage period to ensure the binder is not overheated. If overheated, the polymer will continue to crosslink, thereby affecting binder handling capabilities.
- Avoiding exposing the modified binder to high temperatures for an extended period, as this will result in mixture workability issues.
- Planning and communicating to ensure the material is handled properly.

FDOT found the production and construction of HiMA mixtures is similar to conventional polymer-modified mixtures, and the same best practices generally apply. According to FDOT State Bituminous Materials Engineer Howie Moseley, Florida contractors can consistently achieve the desired level of compaction when using HiMA binders. FDOT's experience suggests that by controlling temperature and minimizing hand work, the laydown and compaction of HiMA mixtures can be completed without any major issues. Contractors have averaged a bonus for in-place density on most FDOT HiMA projects and achieve an average International Roughness Index from 33 to 47 inches per mile at acceptance.

HiMA Potential Benefits

- **Reduces rutting**
- **Delays fatigue cracking**
- **Mitigates crack reflection**
- **Improves durability of open-graded mixtures**

Cost

According to Moseley, on average, the material cost differences when using HiMA mixtures range from an additional $20 to $25 per ton for dense-graded mixtures and $15 to $20 per ton for open-graded mixtures when compared to mixtures using a PG 76-22 binder. FDOT performed a preliminary analysis and concluded that HiMA projects need to last 10 months longer than conventional polymer-modified asphalt projects to pay for the increased cost. FDOT research and preliminary data suggest the expected gain in pavement life will exceed what is needed to offset the additional cost of HiMA.

> **"FDOT has been using HiMA binder for over six years. It has been a valuable tool for mitigating isolated areas of severe rutting and cracking in our dense graded mixtures and premature raveling in our open graded friction courses. We are very satisfied with its performance."**
>
> *—FDOT State Bituminous Materials Engineer Howie Moseley*

Background

FDOT's experience with polymer-modified binders began in the early 2000s, when polymer-modified binders were used in conjunction with the Superpave mix design methodology to address rutting. While rutting deficiencies in Florida were reduced to only a small portion of the pavement network over the next decade, there were still high-stress projects where rutting remained a significant concern. As a result, FDOT started evaluating the possibility of using HiMA binder in some of its mixtures. This was first initiated as a mechanism to address rutting in high-stress areas, but later expanded to include use of HiMA as a method to reduce reflective cracking and raveling in open-graded friction courses.

HiMA mixtures contain binder modified with 7 to 8 percent polymer, most commonly styrene-butadiene-styrene, and typically grade out to a PG 88-22/88-28 or a PG 76E-22/76E-28, depending on the grading system. This amount of polymer is more than twice what is typically used in conventional polymer-modified binders (approximately 3 percent by weight of the binder) (Klutz, 2019). The binder-polymer structure of conventional modified binders consists of asphalt binder with a dispersed swollen polymer phase that improves binder properties. By increasing the polymer content, the structure changes to a swollen polymer with a dispersed asphalt phase, making the resulting binder behave much more like rubber and enhancing cracking resistance and rutting performance (Figure 1).

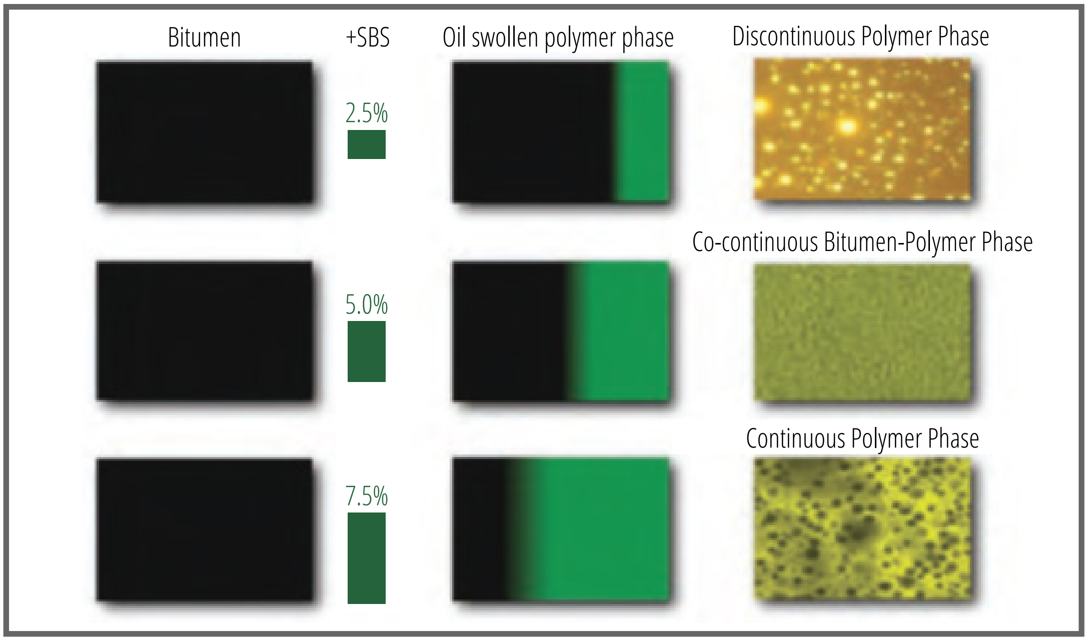


Figure 1. Effect of increasing styrene-butadiene-styrene polymer content on binder/polymer morphology (Source: Kraton Polymers)

One of the driving forces behind FDOT's interest in HiMA mixtures was the positive experiences with this material elsewhere, specifically pavement sections placed at the NCAT Test Track, and by the Oklahoma DOT (ODOT) on Interstate 40 (I 40). These projects provided FDOT with the expectation that the use of a mixture with highly modified binder could be produced and constructed successfully, and that initial performance was good.

During its 2009 to 2012 research cycle, the NCAT Test Track included two full-scale test sections built using HiMA mixtures. Section N7 evaluated whether thickness reduction was viable when using highly polymer-modified mixtures. An adjacent section on the track, Section N8, was initially sponsored in 2006 by ODOT as part of a perpetual pavement study and exhibited extensive cracking after being subjected to 10 million ESALs. It was rehabilitated in the next research cycle in 2009 with a HiMA mill and inlay following a failed rehabilitation using a conventional approach (Willis et al, 2016). The performance observed in these two sections prompted ODOT to use HiMA on a project on I-40 west of Oklahoma City to improve the pavement's rutting resistance and delay reflective cracking. The two-mile pavement section incorporated HiMA in three asphalt mixes and lifts. This project consisted of a more extensive use of highly modified asphalt mixes rather than overlays, as all of these lifts were HiMA modified (PG 76E 28), with the exception of the 0.75 inch open-graded friction course containing a PG 76 28 binder, but no HiMA (Huennen, 2020). However, it is worth noting that by using HiMA, ODOT built a durable, long-term, rut-free pavement using just 8 inches, compared to 12 to 14 inches of conventional design (Figure 2).

Figure 2. HiMA performance on Oklahoma's I-40 (Source: Gary Fitts)

Positive experiences from the NCAT Test Track and ODOT's I-40 project further influenced FDOT to consider using HiMA mixtures on its own pavement network. Several laboratory and accelerated pavement testing studies were conducted along with successful pilot projects that eventually led to statewide adoption of HiMA mixtures for different types of applications.

Research Activities

FDOT has studied the use of polymer modified asphalt binder since the early 2000s, when a successful APT experiment led to the widespread adoption of PG 76-22 asphalt binder to improve the rutting resistance of Superpave mixes. This practice resulted in a steady decrease in rutting levels in FDOT's pavement network; however, localized failures still occurred at locations with concentrated truck traffic and low speeds. This motivated the agency to further research the use of a heavy polymer-modified asphalt binder to achieve better performance.

A follow-up APT study in 2014 evaluated the performance of mixtures containing a polymer-modified binder meeting the FDOT requirements for a PG 82-22 binder compared to the commonly used polymer-modified PG 76-22 and unmodified PG 67-22 (Greene et al., 2014). In FDOT's APT program, accelerated loading is performed using a heavy vehicle simulator (HVS). The HVS is electrically powered, fully automated, and mobile. Rut measurements are made using a laser profiler and fatigue resistance is assessed using strain gauges located at the bottom of the asphalt pavement layer. Figure 3 shows FDOT's APT facility and experimental structures.

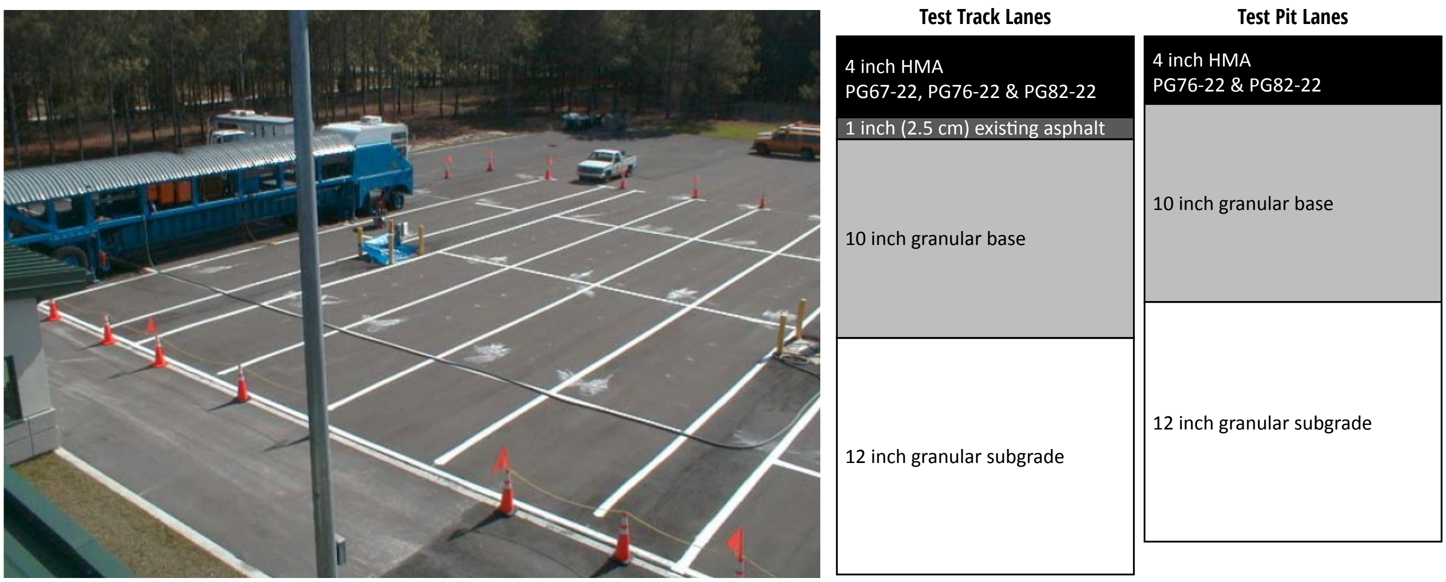


Figure 3. FDOT's HVS and APT tracks and experimental pavement structures (Source: FDOT)

Three test track lanes measuring 12 feet wide and 150 feet long were milled and resurfaced with two 2-inch lifts of three Superpave mixtures for the rut resistance evaluation portion of the study. After 100,000 HVS passes, the amount of rutting in the lanes with the PG 76-22 and PG 82-22 binders was approximately 50 and 80 percent less than the lane without the polymer-modified binder. In addition, two 50-foot test lanes were constructed on test pits to evaluate fatigue resistance. Each test pit consisted of two 1.5-inch lifts of fine-graded Superpave mixture placed directly on the base surface prepared with a prime coat. More than 500,000 HVS passes were applied on the test pits without observation of fatigue cracks. Measured tensile strains at the bottom of the asphalt pavement were considerably lower for both mixtures that used modified binders compared to the mixture using unmodified binder (Greene et al., 2014). According to FDOT, the results indicated that the use of a heavy polymer modified binder improved rutting and cracking performance of asphalt mixtures. This prompted the agency to create a developmental specification to allow the use of PG 82-22 binder.

In 2018, another full-scale experiment was conducted to evaluate the performance of HiMA binder. This time three Superpave asphalt mixtures of similar gradations were placed on the test sections to assess the effect of polymer and binder content. One mixture contained a PG 76-22 polymer-modified binder, another contained HiMA binder at the same effective binder content, and the third also used HiMA binder but with an additional 0.5 percent binder content. The structural sections used in this study consisted of three test lanes milled and resurfaced with two identical 1.5-inch lifts of each of the mixtures for the rutting resistance evaluation, and three test pits resurfaced with two 1.5-inch lifts of each mixture placed directly on the prepared base layer for evaluating fatigue cracking (Figure 4).

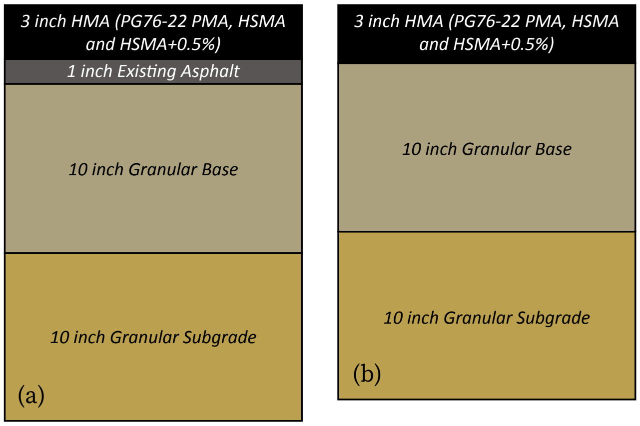


Figure 4. Structural designs for (a) rutting and (b) fatigue cracking test sections (Source: FDOT)

According to FDOT, the results showed that the HiMA binders improved rutting and fatigue cracking performance of the asphalt mixtures. After 100,000 HVS passes, rutting in the HiMA sections was nearly half of that observed in the control section (Figure 5). Similarly, the HiMA sections showed between 20 to 40 percent lower strains than the control section over the recorded temperature range. It was further noted that the additional 0.5 percent binder in the HiMA mixture did not significantly increase rutting as compared to the HiMA mixture at the optimum binder content (Kwon et al., 2018).

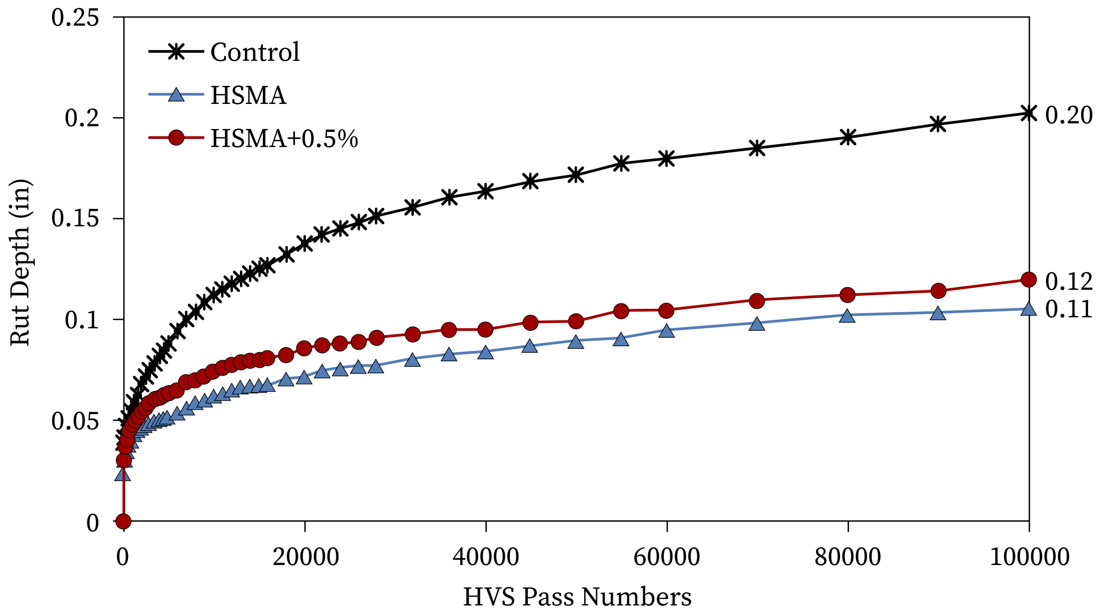


Figure 5. Average rut depth progression (Source: FDOT)

FDOT also sponsored research to determine the structural coefficient of HiMA mixtures. A 2019 study included a laboratory evaluation and full-scale testing of polymer-modified and HiMA mixes to characterize their structural contribution. According to FDOT research, HiMA mixes produced better performance when compared to polymer-modified mixes. An initial fatigue-based structural coefficient of 0.54 was determined for HiMA mixes and verified for other distress modes. The coefficient was also verified using full-scale testing of instrumented experiments in the PaveBox facility at University of Nevada (Habbouche et al., 2019). While the study findings support the use of a coefficient of 0.54 for HiMA mixes in Florida, FDOT has opted to take a more conservative approach and continues to use a coefficient of 0.44 for HiMA mixtures, which is the agency's typical layer coefficient for structural mixtures.

In addition to studying the effect of high-polymer modification on dense-graded mixtures, FDOT has also assessed the mechanical performance and durability of open-graded friction course, containing HiMA binder. The study found that open-graded mixtures with HiMA binder are significantly more durable than those with conventional polymer-modified binder and offered a cost-effective alternative. They were also less prone to aging and had better ductility and cracking resistance (Arámbula et al., 2019).

A University of Florida study conducted in 2020 evaluated the effect of reclaimed asphalt pavement (RAP) on cracking resistance of polymer-modified mixtures, including HiMA. Although RAP has economic and environmental benefits (Williams et al., 2019), FDOT has tried to maximize the amount of HiMA binder in its mixtures, and does not allow the use of RAP in HiMA mixtures. This research supported FDOT's position as it concluded that the incorporation of 20 percent RAP in HiMA mixes would negate the benefits of using the more expensive high polymer binders (Roque et al., 2020).

Implementation

FDOT built one of its first HiMA projects on US-90 in Midway, just west of Tallahassee. The pavement section is in the westbound direction at the I-10 interchange between two large truck stops where the combination of heavy axle loads and slow-moving traffic entering and leaving the truck stops resulted in severe rutting, exceeding 2 inches in some areas. To address these failures, FDOT planned to reconstruct the highway section using portland cement concrete (PCC) pavement. In August 2015, as a temporary maintenance activity to address the severe rutting, FDOT milled the section to a depth of 2.5 inches and replaced it with a dense-graded, 12.5 mm nominal maximum aggregate size (NMAS) friction course HiMA mixture. Although this was meant as a stopgap measure, FDOT said the pavement performed so well that it was left in place and PCC reconstruction was cancelled. After six years of service, FDOT reports that rutting remains minimal and there is very little linear cracking. Figure 6 shows a comparison of rutting performance prior to rehabilitation (2014) and four years after placing the HiMA inlay (2019).

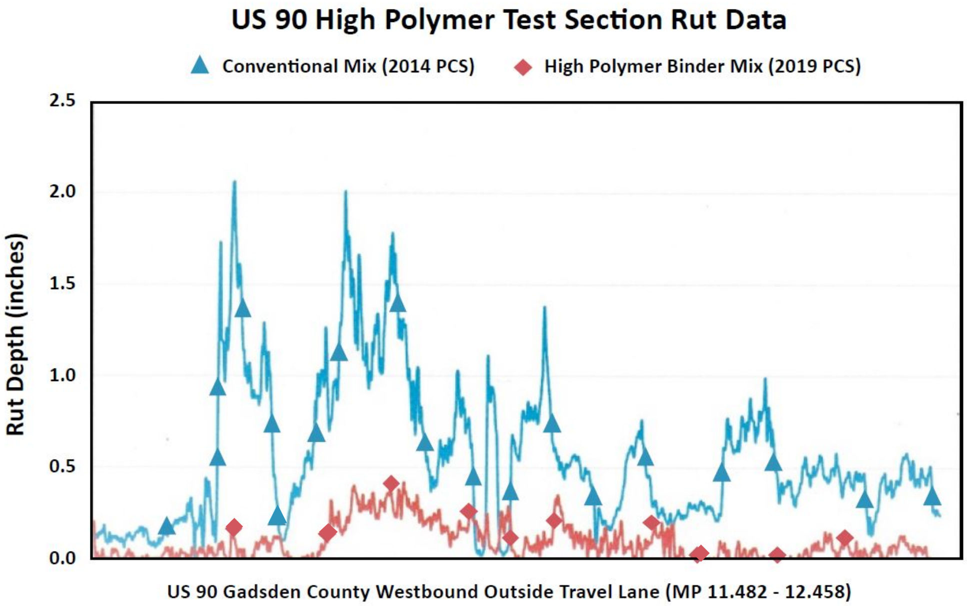


Figure 6. Rutting performance before and after placement of HiMA friction course (Source: FDOT)

Based on US-90 project results and early demonstration projects, FDOT modified its specifications in July 2017 to replace PG 82-22 binder with a HiMA binder—referred to in FDOT specifications as high-polymer binder. To facilitate the transition, the specification changes for the binder did not affect existing projects that were begun prior to this date; however, contractors could switch from PG 82-22 to HiMA binder if desired by way of a no-cost change order to the contract. This helped prevent a contractor from having to use a PG 88-22 and a HiMA binder simultaneously on two paving projects, based on two different letting dates.

FDOT's current HiMA binder specifications reference AASHTO M 332 and contain the standard requirements for asphalt binders but establish more stringent multiple stress creep recovery requirements on the rolling thin film oven test residue, as shown in Table 1 (FDOT, 2021). Only styrene-butadiene-styrene or styrene-butadiene modifiers are allowed in HiMA binders. In addition, the use of polyphosphoric acid is not permitted, as FDOT does not want it to reduce polymer content in the binder.

Test and Method	**Conditions**	**Specification**
Multiple Stress Creep Recovery, $J_{nr,\,3.2}$ AASHTO M 332 & R 92	76°C (HiMA binder only)	$J_{nr,\,3.2} \leq 0.1\ kPa_{-1}$
Multiple Stress Creep Recovery, % Recovery AASHTO M 332 & R 92	76°C (HiMA binder only)	$\%R_{3.2} \geq 90.0$

Table 1. FDOT rolling thin film oven test residue binder requirements.

Since 2015, FDOT has placed more than 500,000 tons of HiMA mixtures on at least 40 projects across the State (Moseley, 2019). FDOT expanded selection criteria to not only address severe rutting in high-stress areas such as truck weigh stations, agricultural inspection stations, and high-volume intersections and interchanges, but also as a repair strategy for bottom-up fatigue cracking and to prevent raveling in open-graded friction courses. In addition, the use of HiMA mixtures is considered an alternative to PCC reconstruction when time to complete the project is a critical factor. To avoid cost issues associated with the storage of HiMA binders, FDOT generally attempts to identify projects with a minimum of 1,000 tons of HiMA mixture (FDOT Design, 2021).

Construction

While overall, FDOT reports the production and placement of HiMA mixtures in Florida has gone quite well, there are still several storage and handling issues that need additional attention to ensure the final product will have the desired characteristics. FDOT considers controlling the storage temperature and limiting the storage period two critical aspects. According to FDOT, the ideal storage temperature for HiMA binder is approximately 320 degrees Fahrenheit. The agency reports it is important to ensure the binder is not overheated or the polymer will continue to crosslink, affecting the binder's handling capabilities. Similarly, exposing the modified binder to high temperatures for an extended period could result in workability issues.

Limited storage time of HiMA binder can pose a challenge for contractors, therefore planning and communication are essential. Since FDOT's early projects, contractors were warned about the potential implications of mishandling the material and were encouraged to discuss specific handling instructions (maximum temperatures, storage time, circulation, etc.) with the material suppliers. There are five HiMA suppliers listed on FDOT's approved products list, with eight distribution terminals as shown in Figure 7.

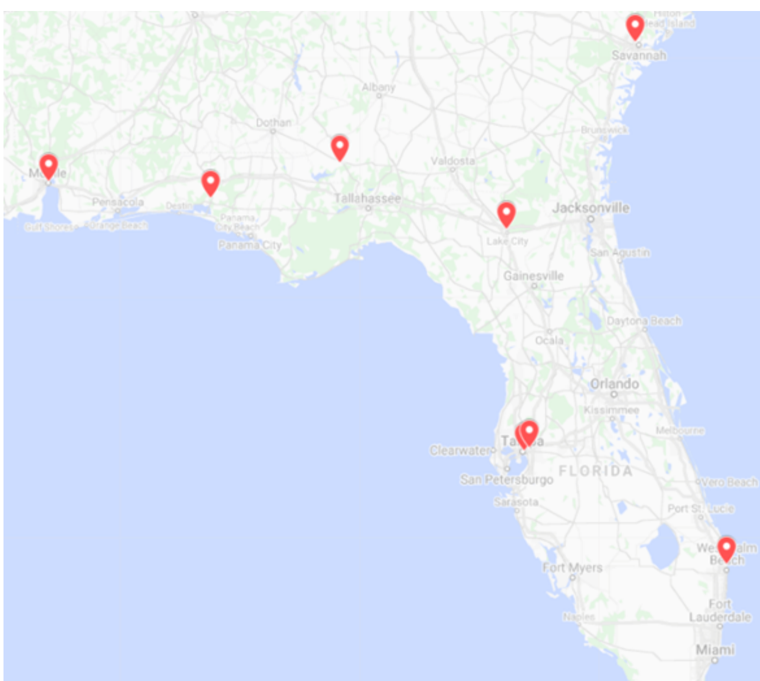


Figure 7. Approved HiMA suppliers for FDOT projects. (Source: FDOT)

Since leftover material can only be stored for a limited time, FDOT has worked with its contracting industry to find options to repurpose HiMA binder and remove it from the contractor's tank in a timely manner. Currently, FDOT allows for leftover HiMA binder to be blended in a contractor's storage tank to produce a PG 76-22 binder. The contractor must receive FDOT's approval prior to blending; follow the blending instructions provided by the HiMA binder supplier; and submit a sample of the blended binder to FDOT for testing and approval prior to its use as a PG 76-22 (FDOT, 2019). In addition, high-polymer binder may be substituted in non-HiMA applications containing up to 20 percent RAP at no additional cost to FDOT. While these may not be cost-effective measures since the cost of HiMA binder is approximately $200 to $300 more per ton than the cost of conventional polymer-modified binder, it may help avoid other problems. According to FDOT, the best approach is to plan material use accordingly.

Because FDOT requires HiMA mixtures be produced with all virgin aggregates (i.e., no RAP), projects will typically require a new mixture design rather than simply substituting the binder type in an existing non-HiMA job mix formula. According to FDOT, use of HiMA does not change the required binder content significantly from mixtures with a conventionally modified PG 76-22 binder. The agency says optimum binder contents are usually between 5 and 6 percent, depending on the aggregate.

FDOT says production and construction of HiMA mixtures is generally like conventional polymer-modified mixes, and the same best practices and guidelines apply. FDOT found that a good bond strength between pavement layers is important, particularly with HiMA mixtures, and utilizes reduced-tracking tack coat materials on all projects. FDOT says maintaining proper temperature is key to completing successful projects. The agency allows a maximum mixing temperature of 340 degrees Fahrenheit when using HiMA binders and contractors have been able to consistently achieve good workability within those limits. It is also important to maintain the mix temperature during transport by keeping the trucks properly tarped (Warren, 2019).

While the use of warm mix asphalt (WMA) additives is somewhat of a common practice in Florida, these are generally used as a compaction aid and/or as an antistrip agent and are not typically associated with reduced mixing and compaction temperatures. FDOT considers HiMA mixtures as WMA if the mixing temperature is 305 degrees Fahrenheit or less; however, HiMA mixes are still produced at around 340 degrees Fahrenheit even with the inclusion of WMA additives.

Laydown and compaction of HiMA mixtures do not pose a significant problem according to paving contractors. By controlling the temperature and minimizing hand work, construction can be completed without major issues. Existing projects consist mainly of milling and inlays, and lifts as thin as 1.25 inches have been placed successfully according to FDOT. An important consideration is that HiMA binder has a higher softening point compared to conventional polymer-modified binder, and therefore the mixtures will stiffen faster. Breakdown rollers should be kept close to the paver and compaction should occur promptly to continuously achieve the target density. Typically, two breakdown rollers are used followed by a finish roller.

FDOT has a percent within limits (PWL) specification for roadway density, with a target of 93.0 percent Gmm, and PWL specification limits of 91.8 to 97. Paving contractors in Florida have been able to achieve the desired compaction without having to modify their rolling patterns. In fact, contractors have averaged a bonus for in-place density on most FDOT HiMA projects. Good smoothness has also been achieved, with an average International Roughness Index for completed projects ranging from 33 to 47 inches per mile at acceptance.

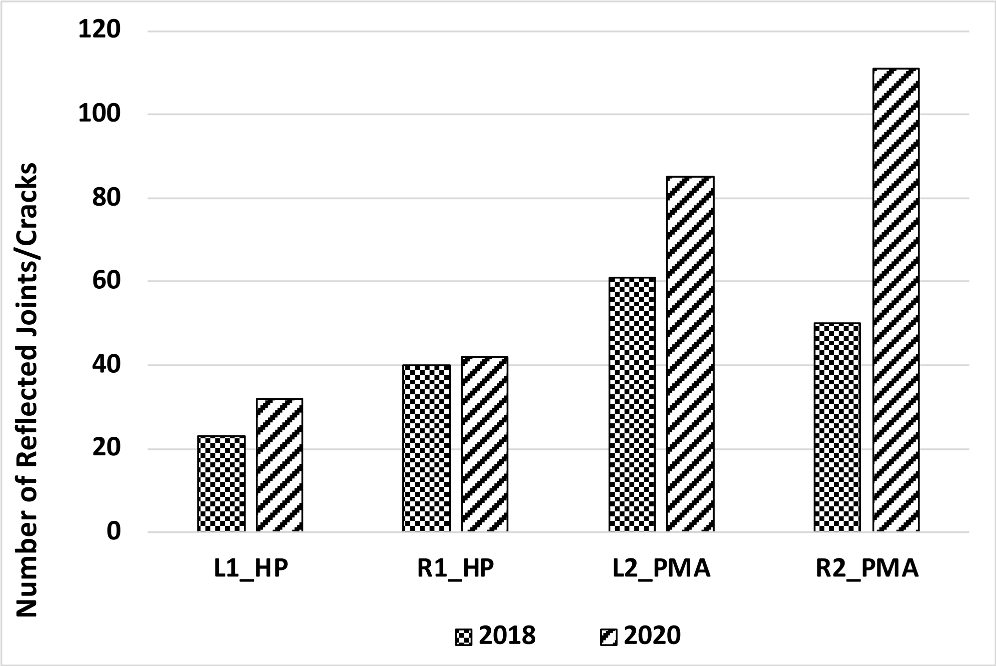
Performance and Evaluation

Figure 8. US-90 Midway project after treatment (Source: Gary Fitts).

On average, the cost difference when using HiMA binder ranges from an additional $20 to $25 per ton for dense-graded mixtures and $15 to $20 per ton for open-graded mixtures when compared to mixtures using conventionally modified PG 76-22 binder. Although existing projects have been in service for 6 years or less, FDOT reports they have performed extremely well to date. Preliminary observations indicate HiMA mixtures can address the problems they were meant to target, but it is not possible yet to estimate exactly how much life the mixtures added to the pavement. FDOT performed a preliminary cost analysis and concluded HiMA projects only need to last 10 months longer than conventional polymer-modified asphalt projects to pay for the cost increase. There is evidence from projects in Florida as well as other States to suggest the HiMA binder could add significantly more years of life than that (Moseley, 2019; Habbouche, J. et al., 2021).

An FDOT special experimental project has been monitoring and evaluating the performance of HiMA overlays to mitigate the reflection of PCC pavement joints since 2017. The project was part of a milling and resurfacing project on SR-45 in Hillsborough County. The existing four-lane pavement structure consisted of a 1-inch 9.5 mm NMAS friction course, 1-inch 9.5 mm NMAS Superpave structural course, and 6 to 9 inches of PCC. The previous resurfacing project had placed a crack reduction geotextile membrane over the PCC construction joints, but the membrane failed, likely due to improper placement, which caused the existing asphalt to spall (Nazef, 2020).

The existing asphalt and geotextile mat were milled down 1.75 inches and replaced with a 2-inch lift of 12.5 mm friction course. The inside passing lanes contained HiMA binder while the outside traffic lanes contained conventional polymer-modified asphalt and were used as a control. It is evident from the FDOT short-term data gathered that the HiMA sections (identified as L1_HP and R1_HP) have less reflective cracking than the standard polymer-modified sections (L2_PMA and R2_PMA), and also have significantly less rutting and better ride quality (Figure 9).



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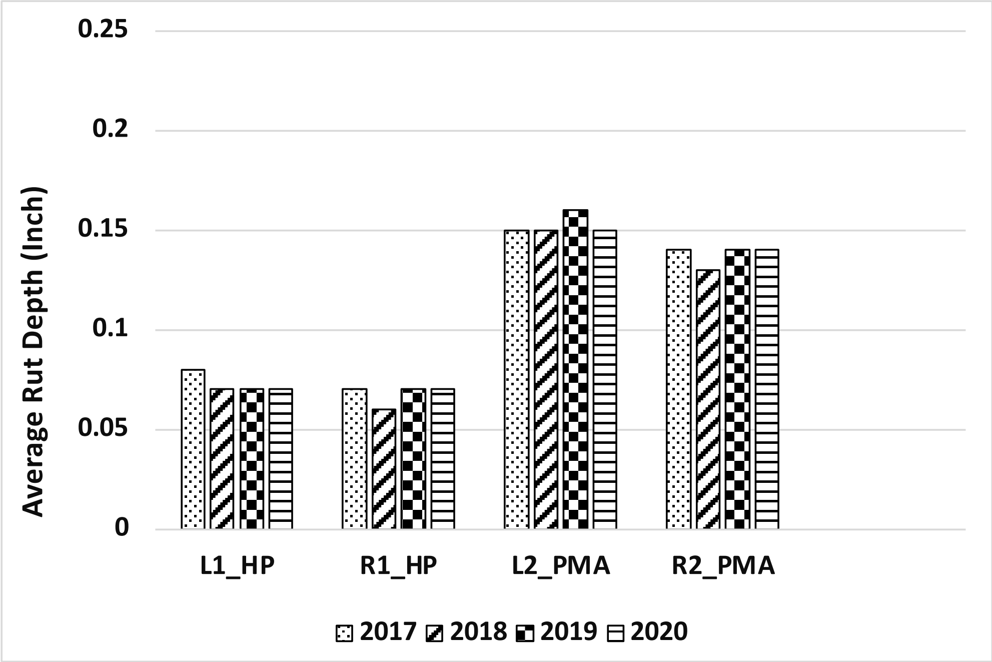

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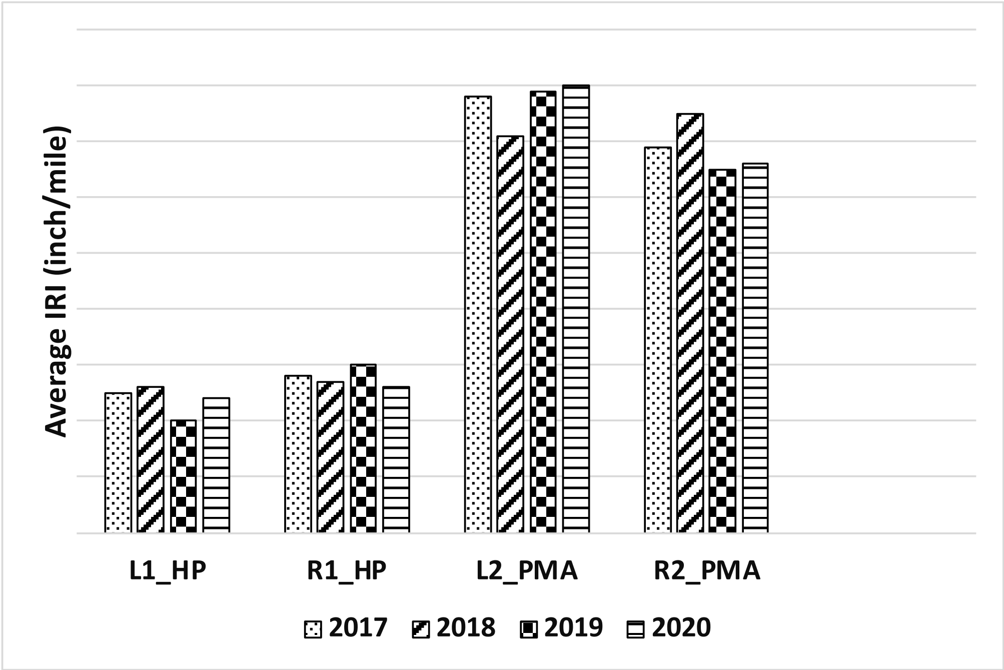

(c)

Figure 9. Performance of experimental sections a) reflective cracking, b) rutting, and c) smoothness (Source: FDOT).

Overall, FDOT has been exceptionally pleased with the performance and apparent cost-effectiveness of HiMA mixtures and will continue to use them on an as-needed basis.

Conclusions and Recommendations

FDOT has successfully used HiMA mixtures to address severe rutting, fatigue, and reflective cracking and raveling. The agency has used HiMA binders in open- and dense-graded friction course layers, as well as intermediate layers successfully and recognizes they could also be used in other mix types. Research and preliminary data from FDOT projects suggest that the expected gain in pavement life will far exceed what is needed to offset the additional cost of this premium mix.

According to Moseley, while initially there was some resistance within the asphalt contracting industry over the use of HiMA mixtures such as concerns with binder handling and storage, pavement compaction, and overall cost of the material, the success of the projects constructed to-date has alleviated many of those concerns.

FDOT projects continue to be carried out without the need for major modifications to the production and construction processes. In general, binder suppliers and asphalt contractors agree that special attention should be given to limiting storage time and controlling mixing, laydown, and compaction temperatures to ensure the mixture remains workable and achieves the desired density. Proper communication and scheduling are also key, with the additional considerations involved in supplying HiMA binder. In general, best practices for construction of standard polymer-modified asphalt mixtures also apply to HiMA mixtures (Warren, 2019).

LIST OF ACRONYMS

- **AASHTO** American Association of Highway Transportation Officials
- **APT** Accelerated pavement testing
- **ESAL** Equivalent single axle load
- **FHWA** Federal Highway Administration
- **FDOT** Florida Department of Transportation
- **HiMA** Highly modified asphalt
- **HVS** Heavy vehicle simulator
- **MTV** Material transfer vehicle
- **NCAT** National Center for Asphalt Technology
- **NMAS** Nominal maximum aggregate size
- **ODOT** Oklahoma Department of Transportation
- **PCC** Portland cement concrete
- **PWL** Percent within limits
- **RAP** Reclaimed asphalt pavement
- **WMA** Warm mix asphalt

REFERENCE

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