Engineering Economics of Highly-Modified Asphalt in Florida

This report examines the cost-effectiveness of using "High Polymer" (HP) binders in Florida. The Florida Department of Transportation has included a High Polymer asphalt binder grade in their Standard Specifications since July 2017. The specification requirements for this grade make it necessary for suppliers to use much higher elastomer contents than are necessary with other binder grades, hence the name. FDOT has funded several research projects evaluating the performance of asphalt mixtures using HP binder. A study conducted at the University of Nevada-Reno recommended the use of a higher AASHTO structural layer coefficient when using HP binders in dense-graded HMA when designing flexible pavements for Florida DOT projects.

Cost per mile estimates available on the FDOT website were identified for three scenarios that closely match the assumed conditions provided in the 2019 FDOT Pavement Type Selection Manual for rural arterial, urban arterial and limited access routes. These estimates include quantities and cost calculations for new construction and pavement rehabilitation. Three unit cost differences ($15, 25 and 35/mixture ton) were assumed when using HP binder compared to mixtures assuming the use of PG76-22. Total project costs were adjusted accordingly for each estimate for new construction and rehabilitation.

Substituting 3 inches of HMA using HP binder, the numbers of allowable 18,000 lb. single axle loads when using HP binders were found using revised AASHTO structural number values. The smallest increase in allowable ESAL was over 40%, so the performance period was adjusted from 16 to 22 years to account for the improved performance provided by the HP binder.

The FDOT Pavement Type Selection Manual prescribes using a 3.5% discount rate over a 40-year analysis period when performing a life cycle cost analysis. Deterministic present worth analyses of agency costs were performed using these assumptions for each case. The results of the analyses show that the use of HP binders is cost-effective when the cost difference in HMA is less than about $34/ton for any of the conditions analyzed. This was greater than the difference in costs observed in published FDOT data.

Introduction, Objective

"Highly-modified" asphalt binders have been used in Florida since 2015. That year, a trial project was built on US 90 in Midway, Florida, where a severely rutted pavement was successfully rehabilitated using a dense-graded hot mix asphalt (HMA) layer with this binder grade. This resulted in additional successful trials and research projects, and ultimately the adoption of a "High Polymer" (HP) binder grade in Section 916 of FDOT's Standard Specifications beginning in July 2017. HP binders may be used in all types of friction course mixtures (Section 337), and in Superpave Asphalt Concrete (Section 334) described in the FDOT Standard Specifications.

The key features of the HP binder specification are the multiple stress, creep recovery (MSCR) requirements, which are much more stringent than other asphalt binder grades included in FDOT specifications. FDOT Section 916 requires a minimum MSCR recovery (AASHTO T350/ASTM D7405) of 90%, and maximum compliance ($J_{nr3.2}$) of 0.1 kPa^{-1} on RTFO-aged material at 76°C. To accomplish this usually requires modifying an asphalt binder using at least 7.5% of an elastomeric polymer, compared with 2.5-3% for PG76-22.

In the twelve months ending on April 30, 2020, the Florida Department of Transportation awarded construction contracts that included over 3.75 million tons of hot mix asphalt. More than 2/3 of the mixture tonnage let to contract for Superpave and Friction Course items required the use of either PG76-22 or High Polymer. Of this, slightly less than 3% used High Polymer binders.

Considering the research results and excellent pavement performance observed when using HP binder, why is there so little use of HP binders on FDOT projects? According to the FDOT Approved Products List, eight asphalt binder terminals were available to supply High Polymer binders for Florida DOT projects in June 2021, so availability should not be an issue. HP binders are more expensive due to the higher polymer content of the binder, but how does this affect the cost of highway pavements over an extended analysis period if they provide improved performance and an extended pavement life?

The objective of this study is to evaluate and compare the life cycle agency costs for HP and PG76-22 mixtures using FDOT procedures and data, using the results of research studies sponsored by FDOT to adjust anticipated rehabilitation schedules for projects using HP binder.

Background

Recent research sponsored by FDOT has demonstrated the performance benefits of using HP binder. Research Report BE321 *(1)* describes a study performed by the University of Nevada-Reno that examined how best to characterize dense-graded HP mixtures for flexible pavement structural design. The structural layer coefficient assumed for new construction for conventional Superpave and dense-graded friction course mixtures is 0.44, as noted in the 2020 Florida Flexible Pavement Design Manual, or FPDM *(2)*. The UNR research study concluded that a value of 0.54 is appropriate for dense-graded HMA layers when using HP binder for Florida materials and conditions.

The FPDM references the 1993 AASHTO Guide for Design of Pavement Structures *(3)* for flexible pavement structural design. Using the 1993 AASHTO Guide a required pavement structural number (SN) is determined that allows for an assumed loss in present serviceability index for the anticipated traffic loading (18,000 lb. equivalent single axle loads, ESAL) and subgrade support conditions (M_R) for a selected reliability level and variability in input parameters.

Pavement Performance

The SN of a flexible pavement structure is calculated as the sum of the products of thickness (inches) and structural layer coefficient for each pavement layer (Equation 1). Layer coefficients defined for use for Florida DOT projects are provided in Table 5.4 of the 2020 Flexible Pavement Design Manual (FPDM). Note that this form of the equation does not include a drainage coefficient, which is included in the 1993 AASHTO Guide.

$$SN_C = (a_1D_1) + (a_2D_2) + (a_3D_3) + \ldots + (a_ND_N) \quad (1)$$

where

SN_C = calculated Structural Number,
a_i = structural layer coefficient for layer i,

D_i = thickness of layer i, in

For the same layer thickness, using a higher structural layer coefficient results in a larger SN_C value. In other words, the same layer configuration would be able to withstand more ESALs. Since cumulative ESALs are a function of time, using a material with a higher structural layer coefficient should result in extended pavement life.

A higher structural layer coefficient could justify reducing the thickness of the asphalt layer, particularly for pavements where the total thickness is constrained. For example, if projected truck traffic is expected to increase on an existing highway that has curb and gutter drainage, it is not possible to strengthen the pavement structure by raising the profile without affecting the surface drainage system. In such a case, existing material could be removed and replaced with HMA using HP binder to increase the SN_C while matching the existing profile.

For most new construction, Florida DOT uses flexible pavement designs with relatively thin asphalt layers. Further reduction of asphalt layer thickness could be unrealistic for practical reasons-even if the pavement design calculation would justify it.

The 2020 Flexible Pavement Design Manual requires a 20-year design period for new or reconstructed flexible pavements. SN requirements are tabulated in the FPDM for different subgrade modulus (M_R) values, traffic conditions (20 year ESAL) and design reliability levels. The impact of replacing 3 inches of dense-graded HMA using PG76-22 with the same thickness using HP can be evaluated by finding the additional number of ESAL that are provided by the increased structural number (0.30). Assuming a growth rate for ESAL, a revised design life can be determined by calculating a new design SN_C, finding the corresponding number of ESAL, and then calculating the number of years to reach the new ESAL.

Three categories of subgrade modulus and three traffic categories were selected for evaluating the effect of replacing 3 inches of HMA using PG76-22 with the same thickness using HP binder. The resulting SN required for these combinations were determined from the FPDM, Table 5.3, which used 90% design reliability (Table 1).

TABLE 1 FDOT Structural Number Requirements for Defined Conditions

	SN Required, R = 90% (FPDM, Table 5.3)		
FDOT Traffic Level	C	D	E
20 yr ESAL	3,000,000	10,000,000	30,000,000
M_R = 5000 psi	4.77	5.65	6.53
M_R = 10000 psi	3.73	4.50	5.27
M_R = 15000 psi	3.19	3.89	4.60

Substituting HP binders for 3 inches of structural HMA increases the SN by 0.30. Adding this to the SN values in Table 1, revised allowable ESAL can be determined as summarized in Table 2.

TABLE 2 Revised Allowable ESAL, Replacing w/3” High Polymer

	Revised ESAL, Replacing 3” PG76-22 with HP		
FDOT Traffic Level	C	D	E
M_R = 5000 psi	4,625,000	14,688,000	42,500,000

M_R = 10000 psi	4,920,000	15,714,000	45,000,000
M_R = 15000 psi	5,222,000	16,317,000	46,250,000

For these assumed conditions, replacing 3 inches of HMA with the same mixture using HP binder would increase the design life by over 40% in all cases.

The 2019 Florida DOT Pavement Type Selection Manual *(4)* provides assumed rehabilitation strategies for use when comparing life cycle costs of pavement structural design alternatives (Table 4). Three roadway classifications are defined, which represent prevalent project conditions in Florida. As noted in the Pavement Type Selection Manual "These scenarios are not intended to indicate the exact future rehabilitation designs, but rather to reflect reasonable strategies and quantities for estimating life cycle cost."

TABLE 4 Flexible Pavement Rehabilitation Scenarios *(4)*

	Rehabilitation Strategy-per Roadway Classification		
Year	Rural Arterial (C)	Urban Arterial (D)	Limited Access (E)
16	Mill 2 inches 3 inches HMA 1 inch Dense Friction Course	Mill 2 inches 1 inch HMA 1 inch Dense Friction Course	Mill 3 inches 4 inches HMA 0.75 inch OGFC
32	Mill 2 inches 3 inches HMA 1 inch Dense Friction Course	Mill 2 inches 1 inch HMA 1 inch Dense Friction Course	Mill 3 inches 4 inches HMA 0.75 inch OGFC

Applying the anticipated increase in service life to the service periods used in Table 4, the number of years before and between rehabilitation activities increases from 16 to 22 years.

The Limited Access (Traffic Level E) classification describes Interstate highways and Florida's Turnpike system. This includes an open-graded friction course (OGFC) surface, which is not assigned a structural number in the FPDM. However, the performance lives of OGFC using PG76-22 and HP are not the same. FDOT sponsored a research project performed by the Texas A&M Transportation Institute (TTI) *(5)* that estimated considerable improvements in time to replacement for OGFC mixtures using HP (Table 5). The improved performance life resulting from using HP binders is reasonably close to what was determined based on the increased SN of HP mixtures, so the timing for rehabilitation using HP mixtures for that scenario was assumed to be the same as for those which do not require the use of an OGFC surface.

TABLE 5 Performance Estimates for FC-5 (OGFC) Mixtures *(8)*

Materials (Aggregate Type-Binder)	Average Lifetime (years)
Granite-HP	22.1
Limestone-HP	20.8
Granite-PG76-22	15.0
Limestone-PG76-22	12.0

Project Costs

The TTI study included a life-cycle cost analysis comparing OGFC using High Polymer binder with PG76-22. That comparison only considered the costs of OGFC using different binders, and did not account for other work that takes place during highway construction and rehabilitation projects. Items such as mobilization, traffic control, pavement markings, etc., should be the same regardless of binder type, but the present value of each intervention are different if the work was performed in different years since there is a discount rate (3.5%) applied to the analysis as per FDOT guidelines. Consequently, it is best to use total project costs, adjusting the total for using different binders instead of only considering the cost of HMA items.

Florida DOT publishes "Cost per Mile" models for a wide range of project types on their website *(6)*. These are generic estimates of the cost per centerline mile used for performing long-range planning. Estimated quantities and unit bid prices are included for each case. Conditions that closely matched the three roadway classifications in the Pavement Type Selection Manual were identified for new construction and rehabilitation activities for each classification (Table 7).

In each case, PG76-22 was indicated as the binder grade for all but incidental construction. Project costs using HP binder are estimated by calculating a revised cost of those HMA items and adjusting the total cost figures accordingly. For simplicity, the costs for the entire quantities of HMA for items requiring PG76-22 were adjusted, rather than attempting to separate them into what would have been required to provide exactly 3 inches of dense-graded HMA. For example, the limited access model assumes a four-inch layer thickness for structural HMA. As a result, the cost figures when using HP binders are slightly conservative (higher) than they would be if the quantities were divided.

TABLE 7 FDOT Cost per Mile Estimates *(9)*

Roadway Classification	Project ID	Description
Rural Arterial	NUR4LN-R-03-BB	New Construction Undivided 4 Lane Rural Road with 5' Paved Shoulders
	RSU4LN-R-13-BB	Milling and Resurfacing 4 Lane Rural Road with 5' Paved Shoulders
Urban Arterial	NUU5LN-U-07-BB	New Construction 5 Lane Undivided Urban Arterial with 11' Travel Lanes and 12' Center Turn Lane and 4' Bike Lanes
	RSU5LN-U-16-BB	Mill & Resurface 5 Lane Urban/Suburban Roadway with Center Turn Lane and 4' Bike Lanes
Limited Access	NDRI6L-R-08-BB	New Construction Divided Rural 6 Lane Interstate with 10' Paved Shoulders Inside and Out
	RSDI6L-R-18-BB	Mill & Resurface 6 Lane Divided Rural Interstate with 10' Paved Shoulders Inside and Out

Two major factors influencing the difference in project bid prices for mixtures using different binders include the cost difference between binder types and the amount of binder used in the mixture. Differences observed on recent FDOT bid tab summaries ranged from $12/ton for FC-5 mixtures to $28/ton for Superpave mixtures. It is important to consider that no reclaimed asphalt pavement (RAP) is allowed for FC-5 (OGFC) mixtures regardless of binder type. FDOT allows Superpave and dense-graded friction course mixtures to contain up to 20% RAP when PG76-22 is specified, but no RAP is permitted when using High Polymer. Using RAP results in a lower virgin binder content, so allowing RAP in PG76-22 mixtures explains the greater differential in unit bid prices for dense-graded mixtures than observed with OGFC.

Cost differences of $15.00, $25.00 and $35.00 per ton of HMA were assumed when using High Polymer in order to develop a relationship between the price offset and present value. As mentioned before, these adjustments were made for all mixture types requiring PG76-22, even when more than three inches of HMA was used in the estimate. The Limited Access classification includes an OGFC surface, which was also changed to HP. The adjusted HMA costs were used to calculate revised total costs per mile for new construction and rehabilitation for each roadway classification, which are summarized in Table 8.

TABLE 8, Project Construction Cost Estimates for Comparative Economic Analysis

Construction Cost Estimates					
Binder Grade	PG76-22		HP Binder		
Roadway Classification	New Const., $1,000/mi	Rehabilitation, $1,000/mi	New Const., $1,000/mi	Rehabilitation, $1,000/mi	ΔHMA cost, $/ton
Rural Arterial	$3,285.19	$1,100.27	$3,400.32	$1,192.46	$15.00
			$3,477.07	$1,253.73	$25.00
			$3,552.82	$1,314.99	$35.00
Urban Arterial	$5,850.02	$1,208.88	$5,996.67	$1,309.64	$15.00
			$6,094.44	$1,376.81	$25.00
			$6,192.21	$1,443.98	$35.00
Limited Access	$6,522.50	$1,961.86	$6,761.74	$2,129.46	$15.00
			$6,921.23	$2,241.19	$25.00
			$7,080.71	$2,352.93	$35.00

Life Cycle Cost Analysis

The values shown in Table 8 were used as inputs to a life-cycle analysis of agency costs using RealCost 2.5 software *(7)*, available from the U.S. Department of Transportation Federal Highway Administration. Cost data shown in Table 8 were used as inputs for calculating the net present value and equivalent uniform annual costs (EUAC) of each alternative using the analysis period and discount rate (40 years, 3.5%, respectively) prescribed in the Florida DOT Pavement Type Selection Manual. The software adjusts for differences in life cycles using a remaining service life calculation at the end of the analysis period.

Results of deterministic agency life cycle cost analyses for the described conditions are summarized in Table 9.

TABLE 9 Agency Costs, PG76-22 vs HP Binder

Roadway Classification	Calculation	Agency Costs, $ X 1000/mile			
			HP Binder		
			ΔHMA, Cost/ton		
		PG76-22	$15.00	$25.00	$35.00
Rural Arterial	Undiscounted	$4,936.04	$4,375.97	$4,502.85	$4,629.72
	NPV	$4,146.95	$3,905.00	$4,007.68	$4,110.36
	EUAC	$194.19	$182.86	$187.67	$192.48
Urban Arterial	Undiscounted	$7,663.34	$7,068.19	$7,220.92	$7,373.65
	NPV	$6,796.58	$6,550.95	$6,677.15	$6,803.34
	EUAC	$318.27	$306.76	$312.67	$318.58
Limited Access	Undiscounted	$9,465.29	$8,504.03	$8,754.93	$9,005.93
	NPV	$8,058.65	$7,662.99	$7,869.77	$8,076.54
	EUAC	$377.36	$358.84	$368.52	$378.20

By evaluating a range of potential cost differences using the different binder grades, relationships between HMA cost difference and net present value (NPV) or Equivalent Uniform Annual Cost (EUAC) can be obtained. A linear relationship between NPV and ΔHMA was identified and used to estimate the cost differences that would result in equal NPV (Table 10).

TABLE 10, Difference in HMA Bid Costs Resulting in Equivalent Net Present Values

Roadway Classification	Relationship	ΔHMA for equal NPV
Rural Arterial	NPV = 10.268 (ΔHMA) + 3751	$38.56
Urban Arterial	NPV = 12.62 (ΔHMA) + 6361.7	$34.46
Limited Access	NPV = 20.678 (ΔHMA) + 7352	$34.17

Highway user costs were not estimated in this study, but the HP binder alternatives would necessarily have lower total user costs since the initial rehabilitation is delayed by 6 years compared to the PG76-22 alternative, and there is only one rehabilitation required over the 40-year analysis period. HMA production and paving operations, as well as the other project costs should not differ based on asphalt binder grade.

As noted before, cost differences observed in FDOT data are less than $30.00 per ton, while the difference needed for equal net present value is well above that. As in the TTI study of FC-5 mixtures, using HP binders is cost-effective for the Florida Department of Transportation.

Summary and Conclusions

The impact of replacing 3 inches of dense-graded hot mix asphalt using PG76-22 asphalt binder with Florida Department of Transportation's "High Polymer" (HP) binder was examined with respect to differences in pavement life and economics. A recent study completed by the University of Nevada-Reno for the Florida DOT recommended assigning a value of 0.54 for the AASHTO structural layer coefficient of structural hot mix asphalt layers using HP. When conventional binders such as PG76-22 are used, a value of 0.44 is required according to the FDOT Flexible Pavement Design Manual (FPDM), which uses the 1993 AASHTO Guide for Design of Pavement Structures for designing flexible pavements.

Structural number (SN_C) requirements were determined for three traffic levels and three subgrade resilient modulus conditions. Substituting 3 inches of dense-graded HMA using HP binder for PG76-22 adds 0.3 to the SN_C for each condition. Using the revised SN_C, the allowable number of ESAL were determined for each condition. The resulting ratio of allowable ESAL when using High Polymer was more than 40% for all cases. This ratio was applied to the performance cycles defined in the Florida Pavement Type Selection Manual, increasing this from 16 to 22 years.

Deterministic present value analyses were performed using FDOT assumptions for rehabilitation strategies and discount rate using RealCost 2.5. The results demonstrated the cost-effectiveness of HP mixtures due to the extended performance period provided by the superior binder.

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