Florida Department of Transportation

Evaluation of Green Colored Bicycle Lanes in Florida

FDOT Office
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EXECUTIVE SUMMARY

In recent years, colored treatment on bicycle lanes and crossings has been gaining popularity in the United States. Although, this practice, has been prevalent in European cities for longer time. It was not until 2011 that the green colored treatment received official interim approval from the Federal Highway Administration (FHWA) for experimental use on bicycle facilities across the country *(1).* The Florida Department of Transportation (FDOT) requested and received permission from FHWA for use of the green colored treatments to be applied at bicycle locations on the State Highway Systems. This study focused primarily on evaluating the friction and texture characteristics of five (5) independent green colored bicycle lane projects consisting of either (1) Epoxy Modified, (2) Thermoplastic, or (3) High Friction Surface Treatment materials in Florida. A total of three types of existing pavement surfaces (concrete, open and dense graded asphalt pavements) were used as substrate for the colored application. These chosen sites include both control test sections representing the bike lanes with limited/no traffic interaction and keyhole sections that represent traffic conflict areas (areas where bicycles and vehicles come into conflict). The friction and texture values were obtained using the Dynamic Friction Tester (DFT) and Circular Texture Meter (CTM), respectively.

Results indicated that all green bike lane projects met the initial friction number requirements for Florida's Patterned Textured Pavements. Minor friction loss was observed at the keyhole sections when compared to the control sections indicative of traffic wear effects. Comparison of friction and texture between years 2015 to 2016 revealed minimal to no change in the texture and friction values at all sites, as expected after one year of in-service traffic. Factorial Analysis of Variance (ANOVA) showed that the type of test section (which includes pavement surface type as well as type of green bike lane material applied and the presence of traffic wear) have significant influence on the friction values. The ANOVA analysis indicated no statistically significant difference in friction from year to year. In addition, based on mean profile depth (MPD) measurements, the interaction between pavement surface type and the bike lane material applied as well as the test year had no significant impact on the surface texture. The presence of traffic was not a significant factor. All these results ultimately may lead to new design criteria permitting a more wide-spread application of green colored bike lanes on the Florida State Highway System.

INTRODUCTION

Background

The AASHTO *Guide for the Development of Bicycle Facilities* defines a bike lane as "a portion of a roadway which has been designated by striping, signing, and pavement markings for the preferential or exclusive use of bicyclists" *(2).* To delineate these lanes, in 2011, the Federal Highway Administration (FHWA) issued an Interim Approval for the optional use of green colored treatment *(1*). This approval grants highway agencies permission to experiment with the use of green colored marking for bicycle lane application. These colored pavements serve as traffic control devices to designate locations where bicyclists are expected to operate and areas where bicyclists and other roadway traffic might have potential conflicts (keyhole) *(1)*. Available data reviewed by FHWA indicated that, although no statistical increase in safety or decrease in crashes has been associated with the use of green bike lanes, positive operational effects such as bicyclists positioning themselves more accurately as they travel through intersections and through conflict areas. Also, both motorists and, more importantly, bicyclists felt safer. From an operational stand, the experimental green colored pavement was considered successful for the bicycle applications *(1)*.

In accordance with the conditions of the interim approval, Florida Department of Transportation (FDOT) requested and received permission from FHWA for use of the green colored treatments to be applied at bicycle locations on the State Highway Systems *(3)*. Conditions that warrant a green colored treatments to be used on bicycle lanes on the State Highway System in Florida are: (a) when a traffic conflict area (keyhole) exists at where a bike lane crosses at right turn lane, or where a channelized right turn lane crosses a bike lane, or a bike lane is adjacent to a dedicated bus bay, (b) a history of 3 or more motor vehicle-bicycle crashes exist at or adjacent to the traffic conflict area over the most recent three-year period, and (c) when conflicts between cyclists and motor vehicles has been observed/documented at an average rate of two conflicts per peak hour. Figure 1 presents a typical green colored bike lane with separate right turn lane. In 2016, FDOT's criteria for application of green colored bike lanes was modified to remove the crash history requirement. The new criteria permits application of green colored bike lanes in conflict areas on roadways with a speed limit of 40 mph or greater, primarily as a result of the study described in this report.

Hunter *et al (4)* reported that intersections and intersection-related locations accounted for 50 to 70% of reported bicycle-motor vehicle crashes. According to their study, colored treatment on bike lanes has been used widely especially in European cities as a countermeasure that has the potential to reduce conflicts and crashes at bicycle-motor vehicle crossings *(4*). Another study by Hunter *et al.* evaluated the use of blue colored bike lane treatment and signage system to delineate selected bicycle-motor vehicle conflict areas in Portland, Oregon. The study used videotaped analysis and found positive behavior changes, as significantly higher numbers of motorists yielded to cyclists and slowed or stopped before entering the blue pavement areas and. more cyclists followed the blue colored bike lane path. As a result of the blue pavement, fewer cyclists turned their heads to scan for traffic or use hand signals, showing increased comfort level. According to the study, majority of motorists surveyed felt safe at the blue colored bike areas *(5)*. No measurable increase in safety was associated with this study, however, and the conclusions were based on the perception of the participants, not on a statistical change in crash rates.

Studies conducted on the addition of red colored treatment on bicycle lanes in the community of Tavares, Florida, to provide visual narrowing and to emphasize their use as a bicycle facility, found that there was no increase in motor vehicle speeds after the addition of the red colored pavement, but also that motorists provided greater passing distance from cyclists when there was no red colored shoulder *(6)*. This study also found no measurable increase in safety, and the operational benefits could be questioned based on assumptions about how cyclists operate most safely in traffic.

Hunter, Srinivasan and Martell *(7)* studied the effectiveness of green colored pavement and accompanying signage used in St. Petersburg, Florida in a bike lane weaving area, where motor vehicles across the bike lane, near an intersection. Operation of motorists and bicyclists at the weaving area was observed and videotaped before and after the green pavement and signing treatments were installed. It was concluded that an increased percentage of motorists yielded to bicycles, and significantly higher percentage of bicyclist scanned for proximate vehicles and signaled their intention to turn right after the green colored pavement has been installed. The study also found the green colored bike lanes were more effective when supported by variable message signs. The study did not find any increase in safety or reduction of crashes associated with the application of the green colored bike lanes. Studies by Sadek *et al. (8)* evaluated the effectiveness of a green, high visibility bike lane and crossing treatment located on a cloverleaf interchange in Vermont through field surveys and videotaping in the vicinity of on- and off- ramps. The study concluded that the green bike lane treatment was associated with a majority of bicyclists using the bike lanes instead of the sidewalk or the road, and the motorists think that the treatment has made them more aware of the potential conflict with bicyclist. Also, the green bicycle lanes and crossings appear to increase both bicyclists' awareness of motor-vehicle and motorists' awareness of bicycles. As with previous studies, the study provided indirect evidence of operational advantages but no direct improvement in safety associated with the installation of the green colored bike lanes.

Most of the previous research studies have focused on the operational effectiveness of green colored bike lanes and/or the effect of high-visibility bicycle lane and crossing treatments and have found no direct correlation between an improvement in safety and reduction in crashes associated with the use of green colored bike lanes.

FDOT recognized the lack of data regarding any real safety benefits from green colored bike lanes as being exacerbated by the general lack of these facilities on State roadways, where they could be adequately monitored. Since the studies do not indicate the green colored bike lanes reduce safety, FDOT considered ways to increase the installation of these facilities, in part to monitor their true safety impacts and to address requests from local governments for greater use of the green colored bike lanes. To avoid potentially creating new safety problems, FDOT wanted to determine whether the green materials create any issues with pavement friction for either cyclists or motorists. Cyclists have noted that thermoplastic, in particular, can be very slippery when wet, so there were concerns about introducing large amounts of these new green colored materials in the bike lane. This led to an effort to research the friction properties of green colored bike lanes.

However, no literature on the frictional performance was found on green colored bike lanes. Consequently, this report focuses on the performance evaluation of green colored bike lanes in terms of friction and texture characteristics.

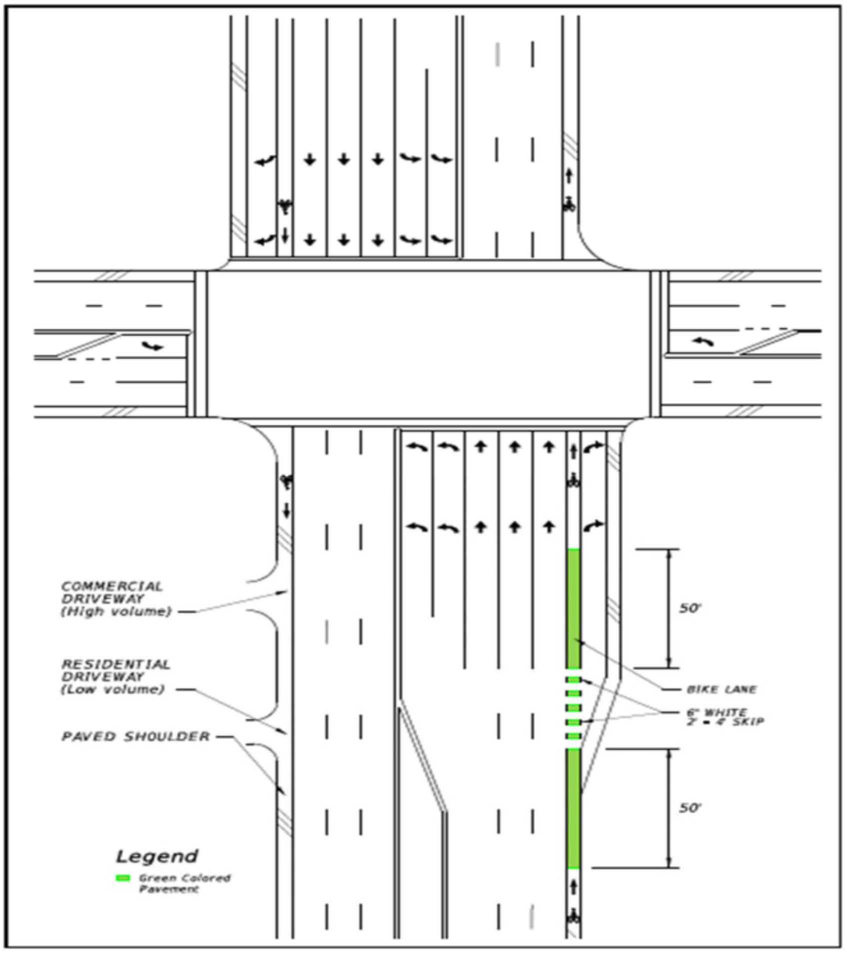


FIGURE 1. Typical Green Colored Bike Lane with Separate Right Turn Lane (3).

OBJECTIVE

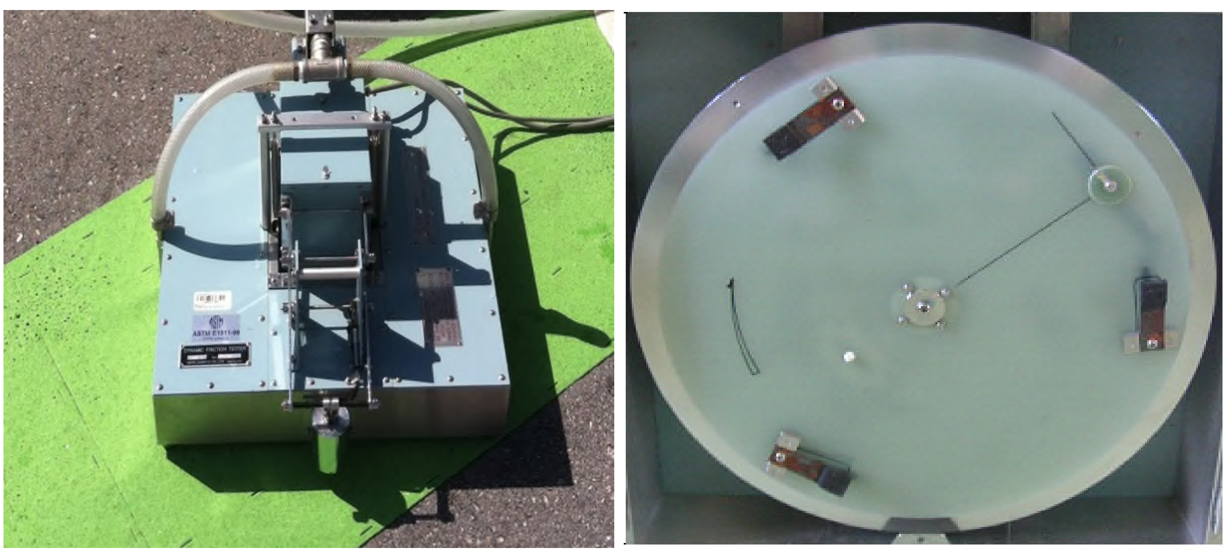
The primary objective of this study is to evaluate the friction and surface texture performance on selected green colored bike lanes in Florida over a period of two years. Five independent green colored bicycle lane projects consisting of either (1) Epoxy Modified, (2) Thermoplastic, or (3) High Friction Surface treatment materials were respectively considered. A total of three types of existing pavement surfaces (concrete, open and dense graded asphalt pavements) were used as substrate for the colored application. These chosen sites include both control test sections representing the bike lanes with limited/no traffic interaction and keyhole sections that represent traffic conflict areas (areas where bicycles and vehicles come into conflict). The friction and texture values were obtained using the Dynamic Friction Tester (DFT) and Circular Texture Meter (CTM), respectively.

TEST EQUIPMENT

Two test devices were used for field testing and evaluation. Dynamic Friction Tester (DFT), which measures the friction in terms of the coefficient of friction as defined in ASTM E 1911 *(9)*, and a Circular Texture Meter (CTM),which measures the surface texture in terms of the Mean Profile Depth (MPD) defined in E 2157 *(10)*. These devices used are briefly introduced herein.

DYNAMIC FRICTION TESTER (DFT)

The Dynamic Friction Tester (DFT) is used to measure the frictional properties of paved surfaces as a function of speed. The DFT equipment and test method are described in ASTM E 1911*(9).* The DFT consists of a horizontal spinning disk fitted with three spring loaded rubber sliders which contact the paved surface as the disk rotational speed decreases due to the friction generated between the sliders and the paved surface. Each slider is spring-loaded to 11.8 *N* (2.65 lbf). A water supply unit delivers water to the paved surface during testing. The water supply is regulated by elevation, and the optimum positioning for the water tank is 0.6 m (1.97 ft.) above the test surface. At this position, the water flow is maintained at 3.6L/min (0.95 gal/min).The torque generated by the slider forces measured during the spin down is used to calculate the friction as a function of speed. Figure 2 shows pictures of the DFT equipment.

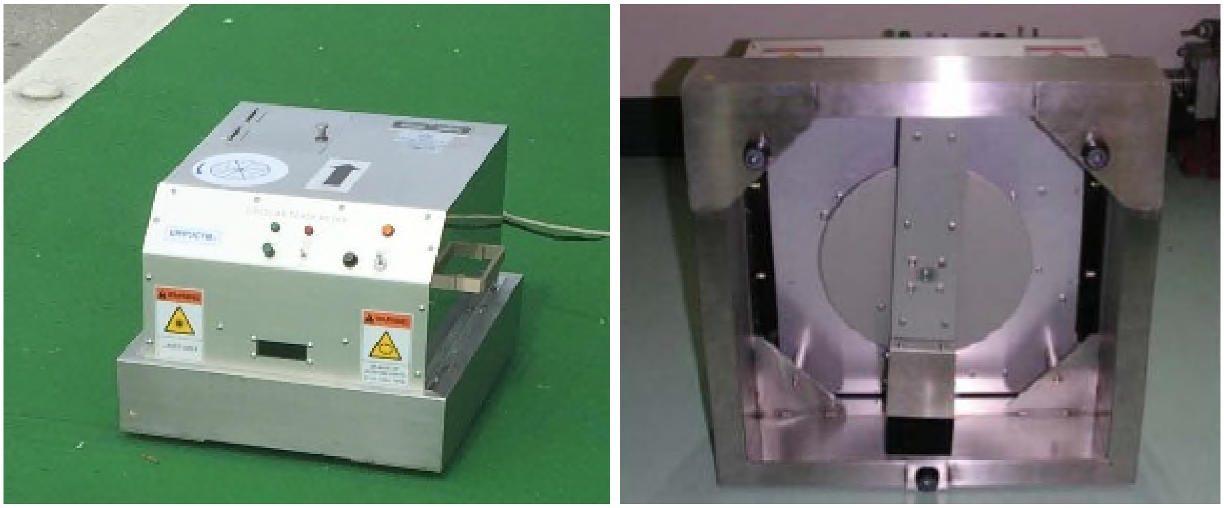


(a) (b)

FIGURE 2. (a) Dynamic Friction Tester (DFT) and (b) the spring loaded rubber slider

CIRCULAR TRACK METER (CTM)

The Circular Texture Meter (CTM) is a laser device used to measure surface texture as standardized in ASTM E 2157 *(10).* The charge-coupled device (CCD) laser displacement sensor is mounted on an arm that rotates around a central point at a fixed distance above the pavement and measures the change in surface elevation. The CTM is a portable device and collects data along a 11.2 in. (284 mm) diameter circle, which yields a measurement length of 35.125 in (892mm), sampled by the data acquisition system to collect 1024 points in one rotation. The CTM equipment is illustrated in Figure 3.



(a) (b)

FIGURE 3. (a) Circular Track Meter (CTM) and (b) the Laser Sensor

PROJECT DESCRIPTION

Five test sites on the state highway systems in two different counties in Florida were selected for this study. The selected sites have been in operation for more than a year and have green colored bike lanes of different treatments consisting of either Epoxy Modified, Thermoplastic, or High Friction Surface Treatment. A total of three types of existing pavement surfaces (concrete, open and dense graded asphalt pavements) were used as substrate for the colored application (Table 1). Figure 4 shows a typical test plan used for the field testing and evaluation. As shown, the test section for each bike lane was divided into two sections, namely a control test section representing the bike lane with limited/no traffic interaction and a keyhole section that represent a traffic conflict area (conflict between motor-vehicle and bicyclists). Three tests were conducted on the control test section, and six at the keyhole test section. The keyhole test section has 3 tests performed on the green colored stripes (keyhole on-stripe) and the other 3 on the existing untreated pavement surface between stripes (keyhole off-stripe).

Both DFT and CTM tests were performed at each test location shown in the test plan. Data was obtained for two years (2015 and 2016) to evaluate the friction and texture performance. For the DFT test, friction values in terms of DFT (expressed as coefficient of friction) at 20mph (30km/h), 30mph (50km/h) and 40 mph (60km/h) were recorded, whiles the surface texture measured in terms of the mean profile depth (MPD) were obtained from the CTM test. Field test results for the five test sections obtained for two years are presented in the following section of this report.

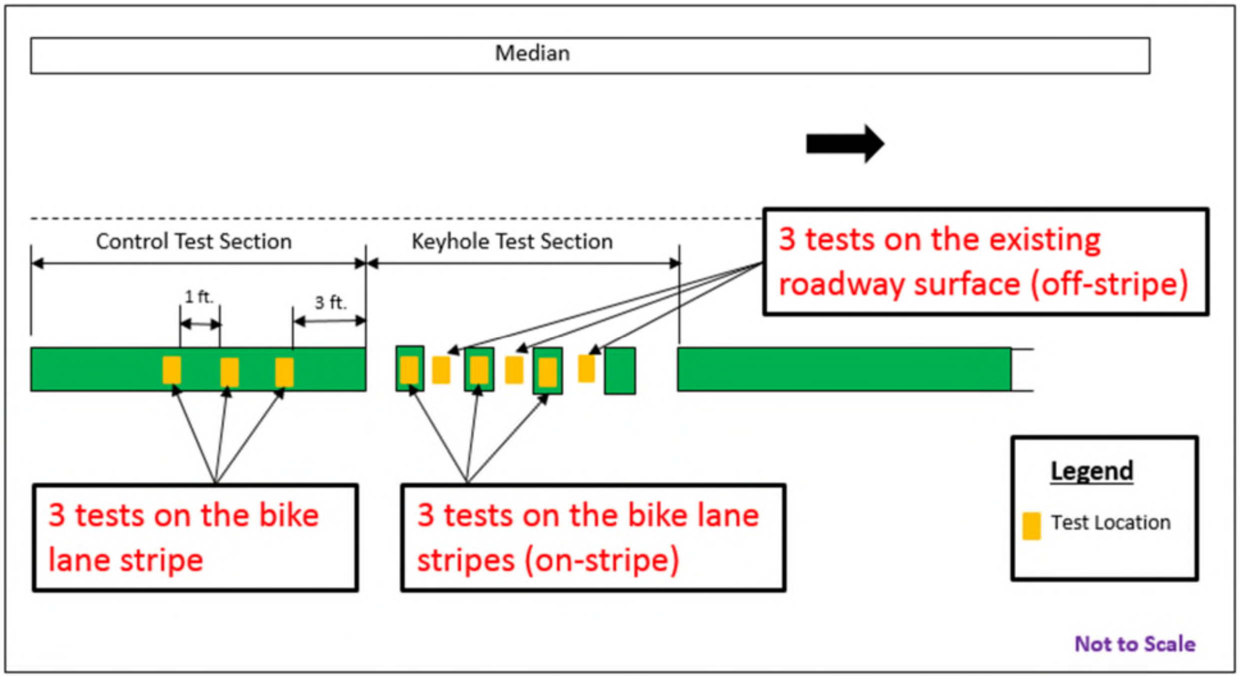
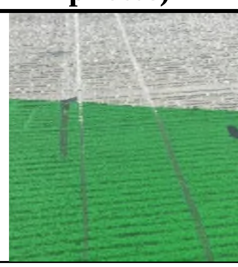
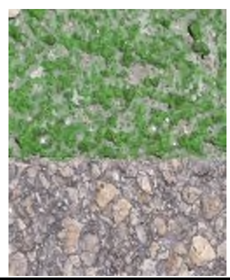


FIGURE 4. Typical Test for the Green Colored Bike Lane

TABLE 1. Green Colored Bicycle Lane Test Matrix

Test Location	Existing Surface Type	Type of Bike Lane Treatment	Green Colored Paints (field photos)	Number of Tests per Equipment	
				DFT	CTM
Site 1 – Lehman Causeway	Rigid Pavement, Transverse Grooved	Epoxy Modified Coating		9	9
Site 2 – Julia Tuttle Causeway onto I-95	Dense Graded AC	Epoxy Modified Coating		9	9

Test Location	Existing Surface Type	Type of Bike Lane Treatment	Green Colored Paints (field photos)	Number of Tests per Equipment	
				DFT	CTM
*Site 3 – MacArthur Causeway	Dense Graded AC	Thermoplastic		18	18
Site 4 – Pineda Causeway	Open Graded AC	High Friction Surface Treatment (HFST)		9	9
Site 5 – Rickenbacker Causeway	Open Graded AC	Epoxy Modified Coating		9	9

*Testing was conducted at both the entrance and exit ramps

TRAFFIC INFORMATION

The cumulative traffic information obtained for the five test sites is presented in Table 2. Pineda Causeway (Site 4) recorded the highest cumulative traffic compared to the other test sites for the two-year period. MacArthur Causeway shows the lowest cumulative traffic.

TABLE 2. Traffic Information for the five test sites

Date Tested	Site 1 (Lehman)	Site 2 (Julia Tuttle)	Site 3 (McArthur)	Site 4 (Pineda)	Site 5 (Rickenbacker)
	Cumulative One Way Traffic (17000 AADT)	Cumulative One Way Traffic (17000 AADT)	Cumulative One Way Traffic (1,800 AADT)	Cumulative One Way Traffic (22,000 AADT)	Cumulative One Way Traffic (17,500 AADT)
9/13/2016	6,205,000	6,205,000	657,000	8,030,000	6,387,500
6/10/2015	0	0	0	0	0

DATA ANALYSIS AND RESULTS

It is important to note that there been no studies conducted on the evaluation of friction/surface texture characteristics on colored bicycle lanes. This study considered several different types of pavement surfaces (rigid, dense graded friction course, open graded friction course). Florida Department of Transportation developed a test method FM 5-592, Patterned Textured Pavement, for measuring friction on patterned pavements. This test method covers the procedures for evaluating the friction resistance of patterned/textured surfaces used on crosswalks over asphalt and concrete surfaces using the Locked Wheel Friction Tester and Dynamic Friction Tester *(11)*. Table 3 shows the minimum friction requirements. This test method has previously developed equations for converting friction values between the Locked Wheel Tester and the Dynamic Friction Tester. Yearly performance monitoring at each test site is presented in the following sections.

TABLE 3. Friction Number Table

FN40R	FN30R	FN20R	DFT40
22	26	30	20
23	27	31	21
24	28	32	23
25	29	34	25
26	30	35	26
27	31	36	28
28	33	37	29
29	34	38	31
30*	35*	39*	32*
31	36	40	34
32	37	41	36
33	38	43	37
34	39	44	39
35**	40**	45**	40**
36	41	46	42
37	42	47	43
38	43	48	45
39	44	49	46
40	45	50	48
41	46	52	50
42	47	53	51
43	48	54	53
44	49	55	54
45	50	56	56

* Minimum friction numbers required for inventory cycles of patterned crosswalks.
**Minimum friction numbers required for new construction and 3-year APL test decks for patterned crosswalks.

Site 1 – Lehman Causeway

Lehman Causeway test site is identified as a rigid pavement with transverse grooved surface texture. The colored bike treatment is an epoxy modified green colored coating. Figures 5 and 6 present the results of yearly comparisons of the coefficient of friction measured at 40 mph (DFT40) and the surface texture (MPD), respectively. As shown, the DFT40 at both the control and keyhole on- and off-stripe sections meet the minimum friction number requirements of 40 as specified in FM 5-592, Friction Measuring Protocol for Patterned Pavements. Overall friction decreased for year 2016 when compared to 2015 at the control and keyhole (on- and off-stripes) sections due to traffic effects. Overall average texture measurements across all sections indicate a decrease in MPD values in year 2016 when compared to 2015. Detail DFT and CTM test results for year 2015 and 2016 are presented in Appendices A and B, respectively.

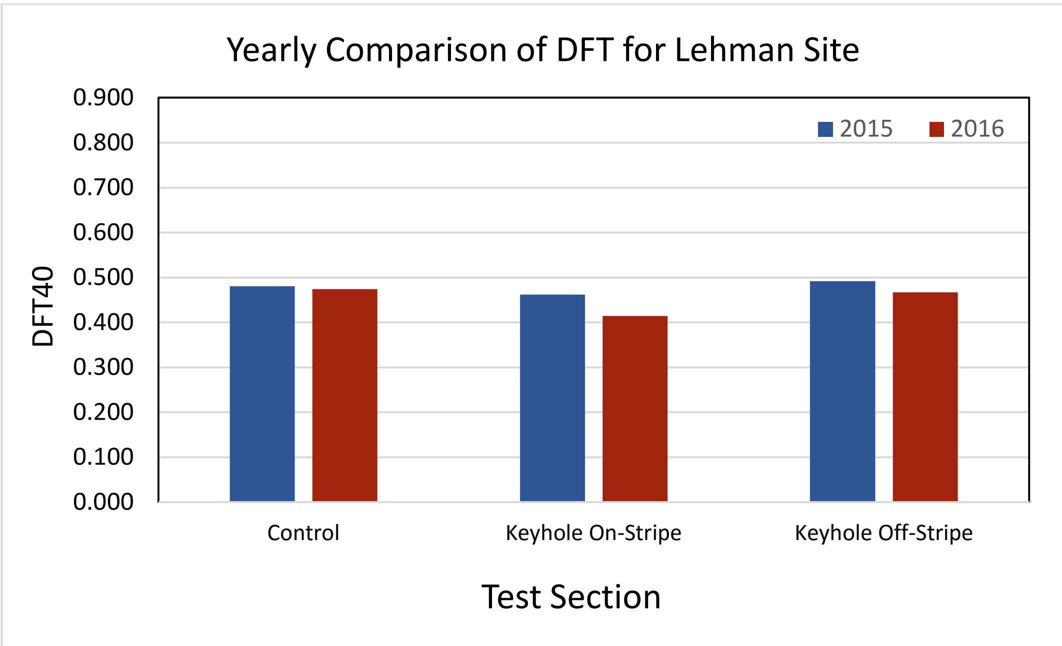


FIGURE 5. Yearly Comparison of DFT40 for Lehman Site

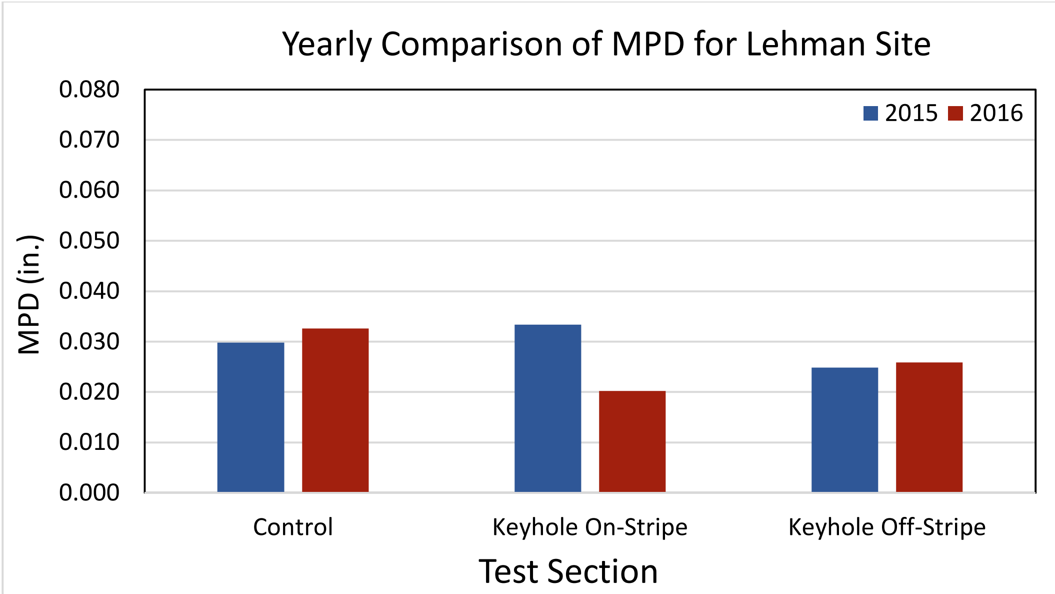


FIGURE 6. Yearly Comparison of MPD for Lehman Site

Site 2 – Julia Tuttle Causeway

Julia Tuttle Causeway test site is a dense graded friction course surface with an epoxy modified green colored coating treatment for the bike lane. Figures 7 and 8 present the results of yearly comparisons of the coefficient of friction measured at 40 mph (DFT40) and the surface texture (MPD), respectively. As shown, the DFT40 at both the control and keyhole on-stripe sections meet the minimum friction number requirements of 40 as specified in FM 5-592, Friction Measuring Protocol for Patterned Pavements. Friction values at the keyhole off-stripe section were lower than normal ranges. No change in friction values was observed at the keyhole on- and off-stripes over the two year period, however there was a slight increase in friction from year 2015 to 2016 at the control section. The friction value at the control section is higher than at the keyhole off-stripe section due to traffic effects. Overall average texture measurements across all sections indicate a slight decrease in MPD values in year 2016 when compared to 2015. Detail DFT and CTM test results for year 2015 and 2016 are presented in Appendices A and B, respectively.

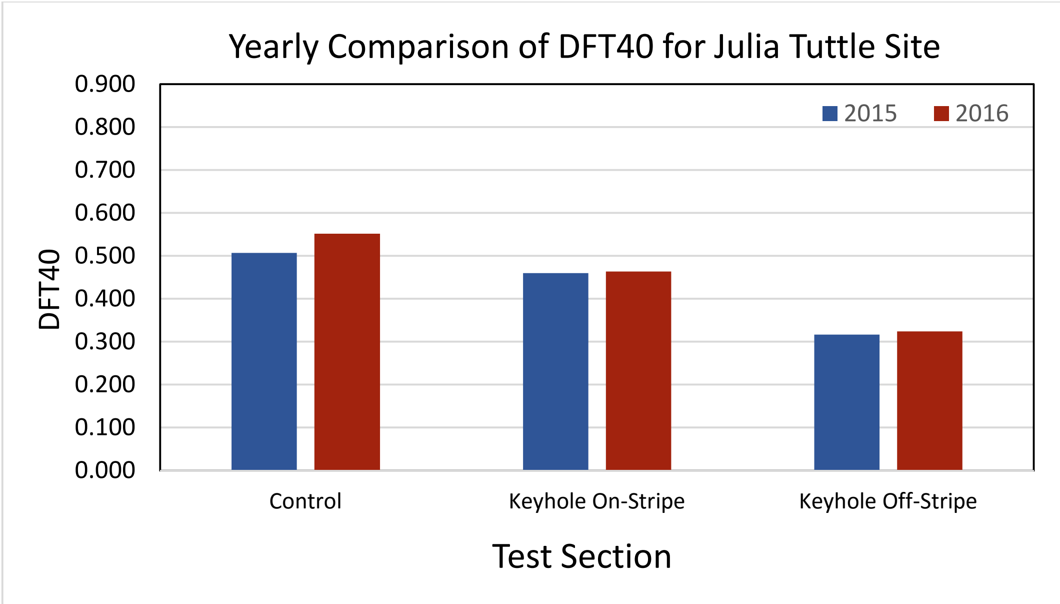


FIGURE 7. Yearly Comparison of DFT40 for Julia Tuttle Site

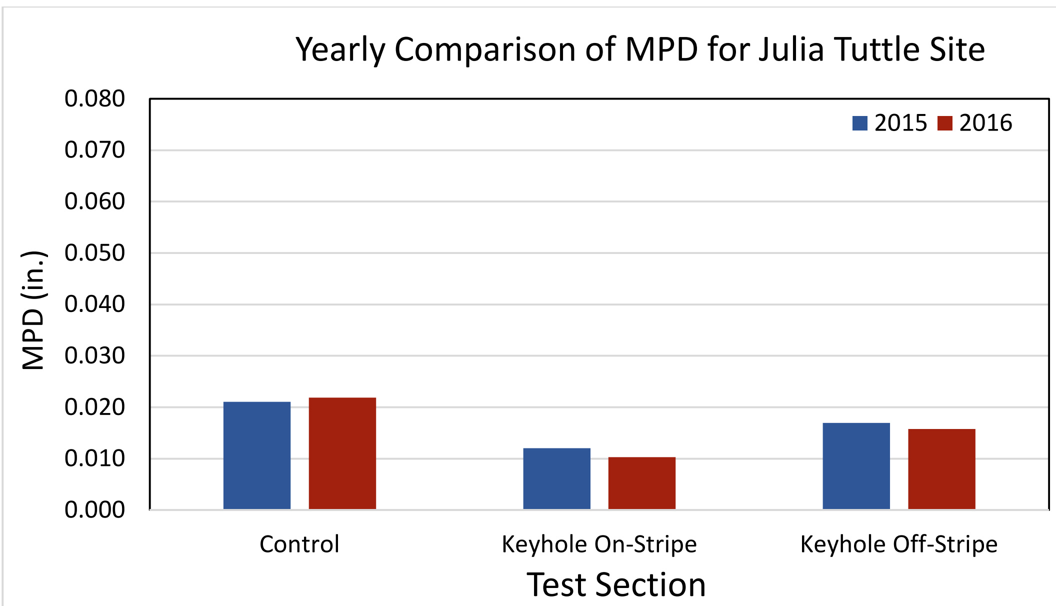


FIGURE 8. Yearly Comparison of MPD for Julia Tuttle Site

Site 3 – MacArthur Causeway

MacArthur Causeway test site is identified as a dense graded friction course surface with a thermoplastic green colored treatment for the bike lane. Tests were conducted at the entrance and exit ramps at this site. Figures 9 to 12 present the results of yearly comparisons of the coefficient of friction measured at 40 mph (DFT40) and the surface texture (MPD), respectively. As shown, the DFT40 at both the control and keyhole on- and off-stripe sections meet the minimum friction number requirements of 40 as specified in FM 5-592, Friction Measuring Protocol for Patterned Pavements. Slight decrease in friction values was observed at the keyhole (on- and off-stripes) than the control sections over time due to traffic effects at both the entrance and exit ramps. Overall average texture measurements across all sections at the entrance ramp indicate a slight increase in MPD values in year 2016 when compared to 2015. However, at the exit ramp there was no change in surface texture over the two year period. Detail DFT and CTM test results for year 2015 and 2016 are presented in Appendices A and B, respectively.

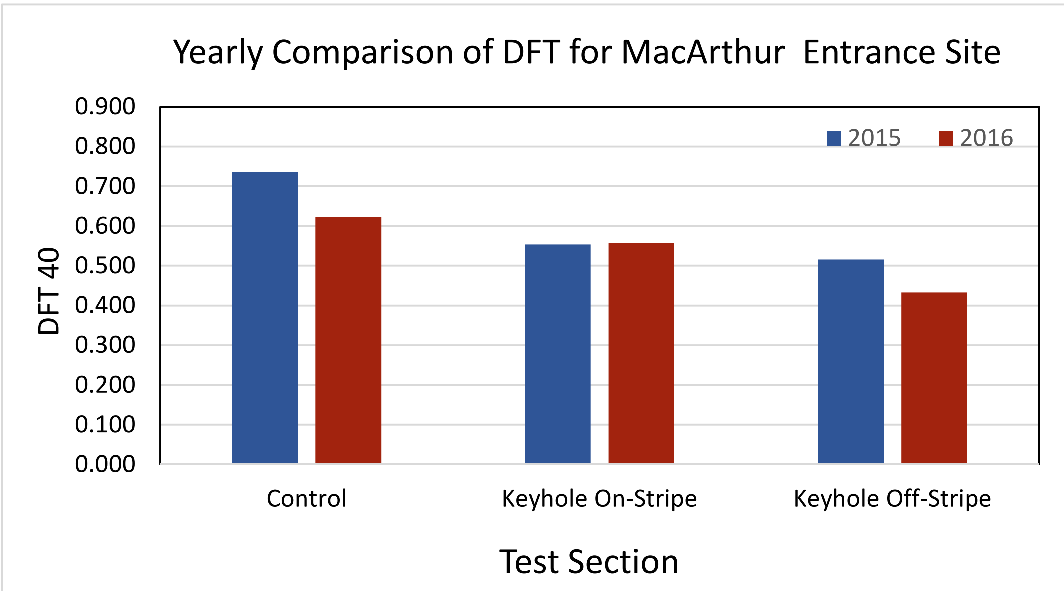


FIGURE 9. Yearly Comparison of DFT40 for MacArthur Entrance Site

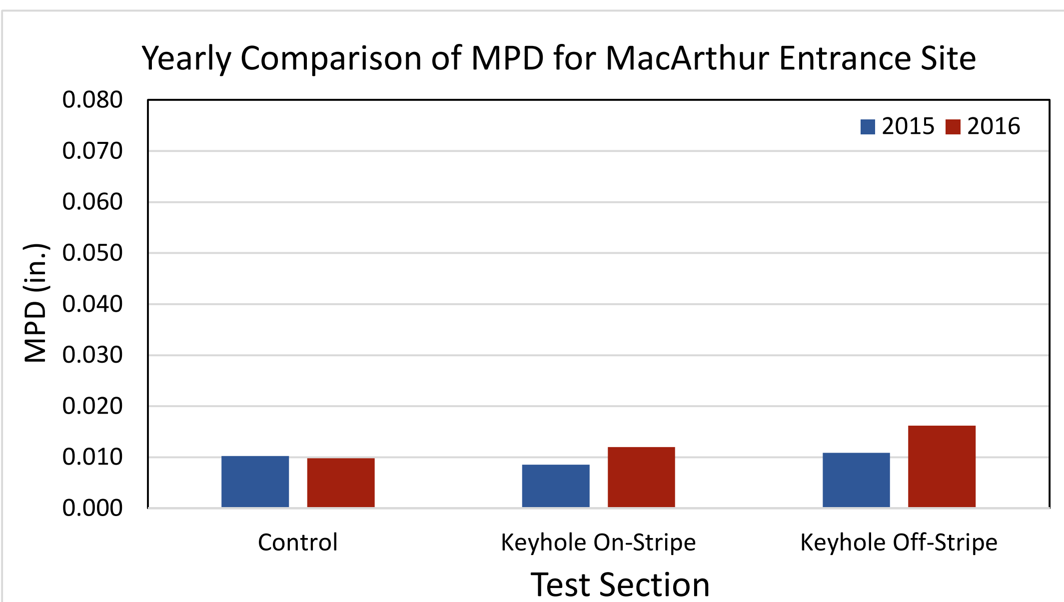


FIGURE 10. Yearly Comparison of MPD for MacArthur Entrance Site

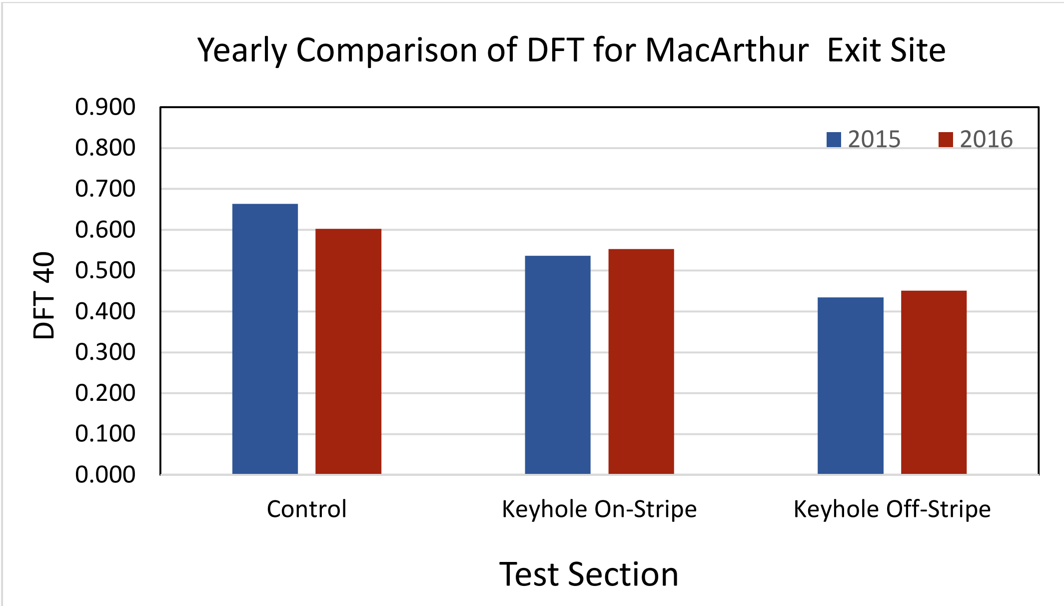


FIGURE 11. Yearly Comparison of DFT40 for MacArthur Exit Site

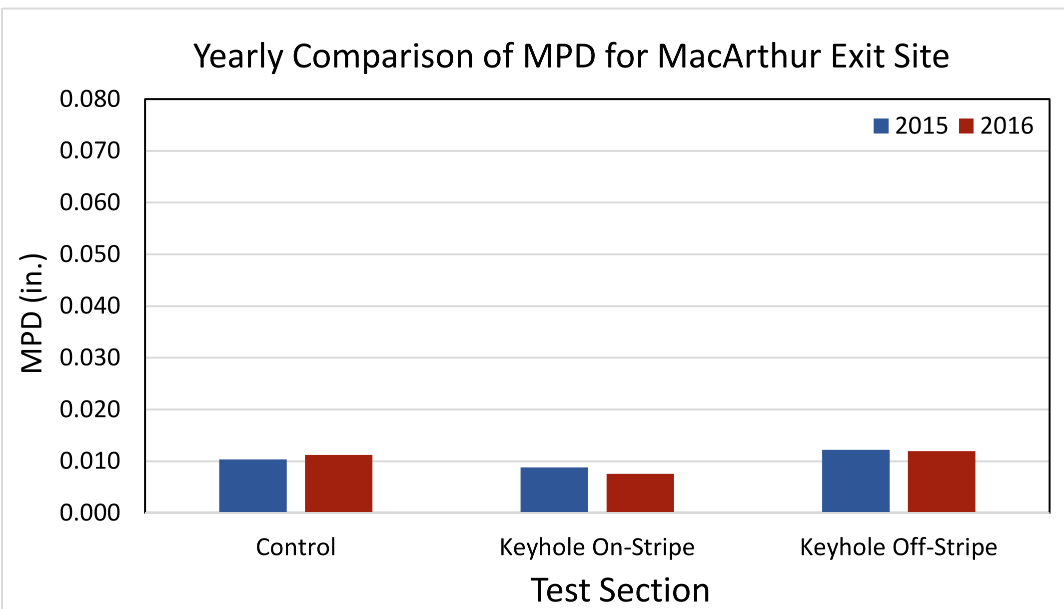


FIGURE 12. Yearly Comparison of MPD for MacArthur Exit Site

Site 4 – Pineda Causeway

Pineda Causeway test site is identified as an open graded friction course surface with a high friction surface treatment (HFST) application for the green colored bike lane. Figures 13 and 14 present the results of yearly comparisons of the coefficient of friction measured at 40 mph (DFT40) and the surface texture (MPD), respectively. As shown, the DFT40 at both the control and keyhole on-stripe sections meet the minimum friction number requirements of 40 as specified in FM 5-592, Friction Measuring Protocol for Patterned Pavements. However, friction value on the keyhole off-stripe section was lower than normal ranges. Friction values decreased slightly over time at the keyhole on- and off-stripes compared to the control section due to traffic effects. Overall average texture measurements across all sections indicate a slight increase in MPD values in year 2016 when compared to 2015. Detail DFT and CTM test results for year 2015 and 2016 are presented in Appendices A and B, respectively.

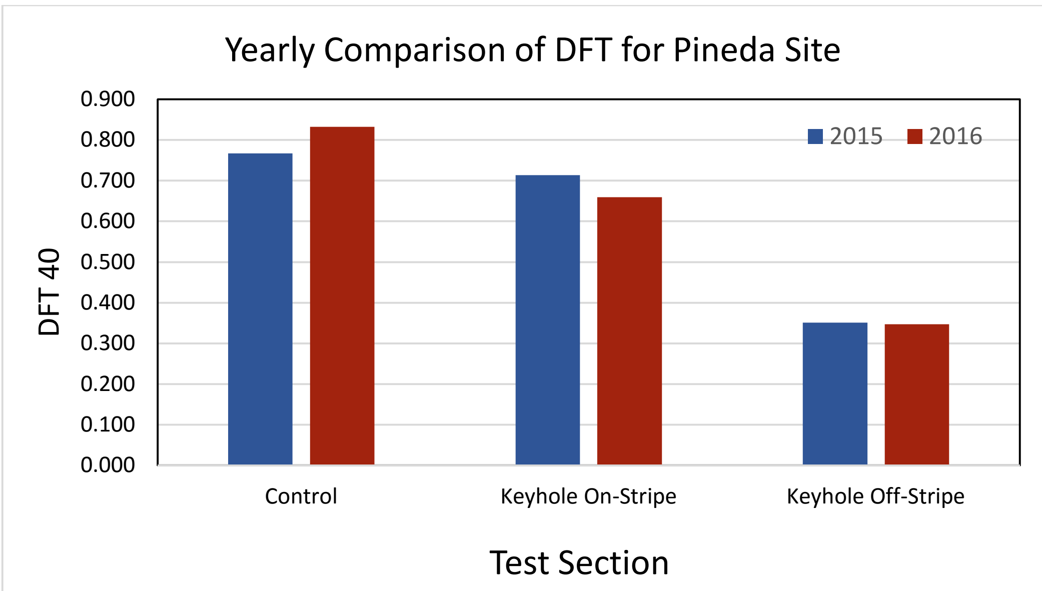


FIGURE 13. Yearly Comparison of DFT40 for Pineda Site

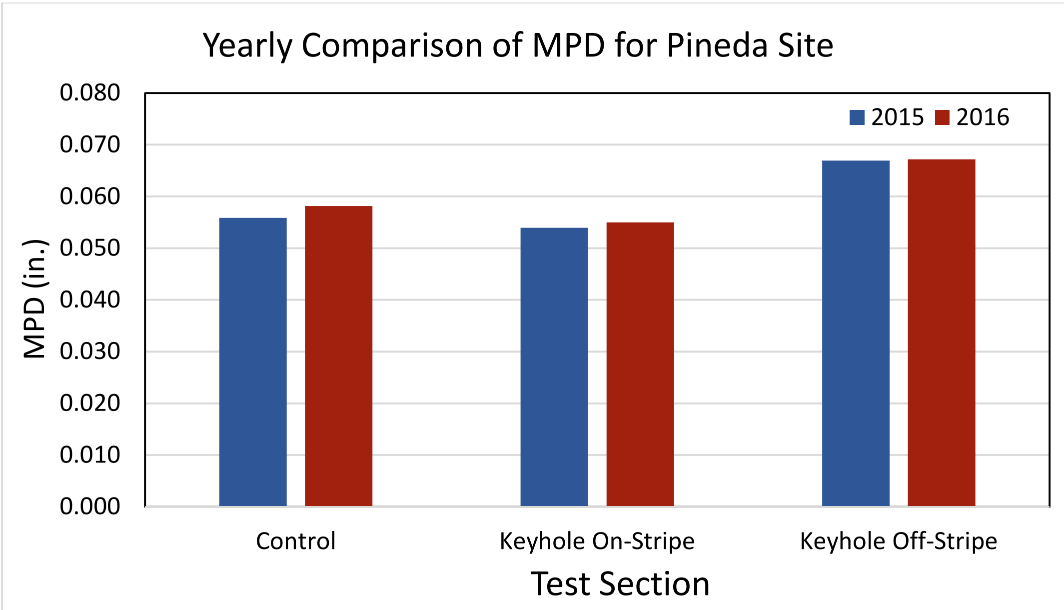


FIGURE 14. Yearly Comparison of MPD for Pineda Site

Site 5 – Rickenbacker Causeway

Rickenbacker Causeway test site is identified as an open graded friction course surface with an epoxy modified green colored coating treatment for the bike lane. Figures 15 and 16 present the results of yearly comparisons of the coefficient of friction measured at 40 mph (DFT40) and the surface texture (MPD), respectively. As shown, the DFT40 at both the control and keyhole on- and off-stripe sections meet the minimum friction number requirements of 40 as specified in FM 5-592, Friction Measuring Protocol for Patterned Pavements. Friction values decreased slightly in year 2016 when compared to year 2015 at the keyhole on-stripe. However, friction value at the off-stripe keyhole section slightly increased in year 2016 compared to 2015. Overall average texture measurements across all sections indicate a decrease in MPD in year 2016 when compared to 2015. Detail DFT and CTM test results for year 2015 and 2016 are presented in Appendices A and B, respectively.

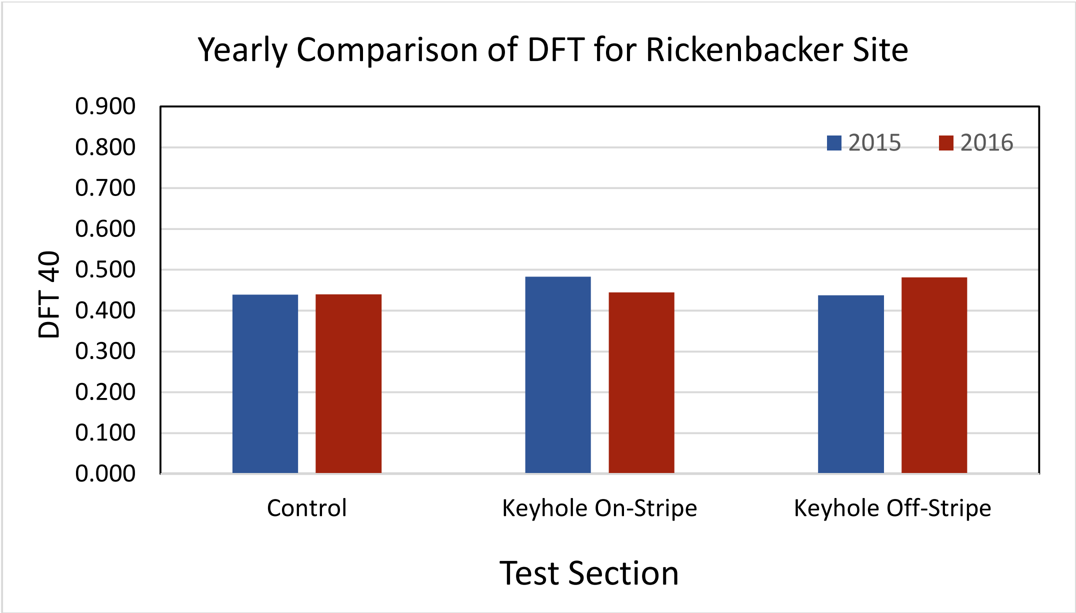


FIGURE 15. Yearly Comparison of DFT40 for Rickenbacker Site

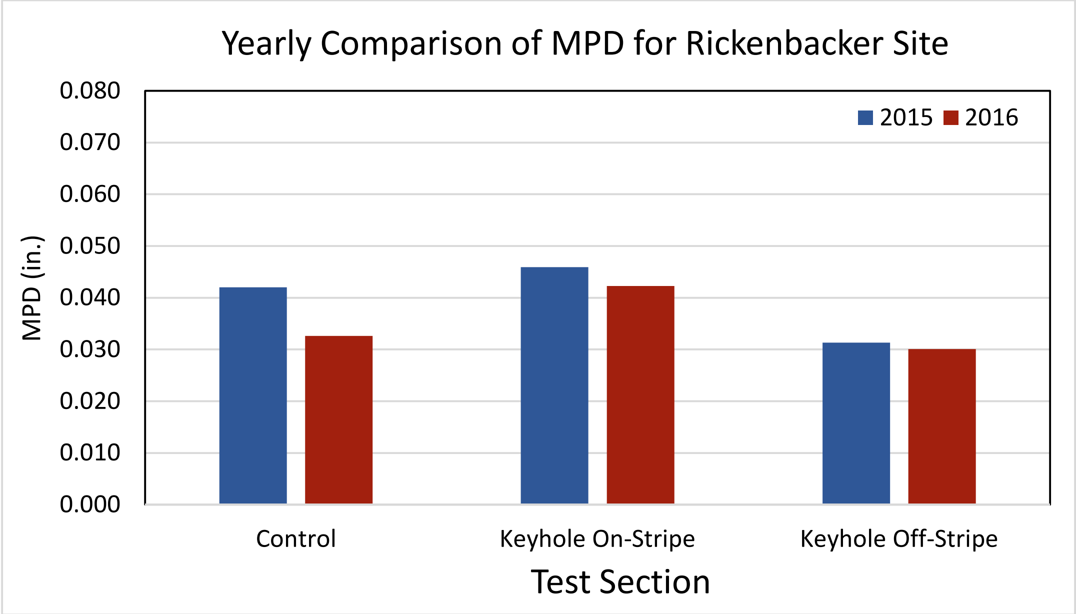


FIGURE 16.Yearly Comparison of MPD for Rickenbacker Site

Statistical Analysis

In order to investigate factors that may affect the friction properties and surface texture characteristics of green bike lanes, a two-way factorial ANOVA analysis was performed. The two-way ANOVA analysis was conducted to check whether the type of test section (which includes features with/without traffic wear and green material applied) and the year (2015 vs 2016, which includes features of traffic and environmental influence) have significant influence on DFT40s and MPDs or not. The null hypothesis (H_0) was that the type of test section, test year and their interactions have no significant influence on the friction at a significance level of α (α = 0.05, for this study), whereas the alternative hypothesis (H_a) was that these factors and their interactions have significant influence on the friction numbers. The key index used to interpret the ANOVA results was the p-value which evaluates whether the null hypothesis is true or not. In other words, a low p-value (less than 0.05) would indicate that there is significant difference between test groups while a high p-value (greater than 0.05) would indicate otherwise.

The friction measurements of both the control and keyhole sections from all five test sites were used as observations in the ANOVA and the results are presented in Table 4. Based on the p-values, it can be concluded that there is no significant difference between test year 2015 and year 2016 in terms of friction measurements. However, the type of test section has a significant influence on the friction measurements, which means that the friction measurements are affected by whether the section received green material and/or experienced traffic wear or not. The interaction between test section and test year has no significant influence on the friction measurements.

TABLE 4. ANOVA Table for Friction DFT 40

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Test Section (Control vs Keyhole)	0.1803	2	0.0901	8.0598	0.0016	3.3158
Year (2015 vs 2016)	0.0015	1	0.0015	0.1353	0.7155	4.1709
Interaction	0.0002	2	0.0001	0.0101	0.9899	3.3158
Within	0.3355	30	0.0112			
Total	0.5175	35				

The significance of test section and test year on the surface texture measurements (MPD) was also tested using a two-way ANOVA analysis. The MPD measurements of both control and keyhole sections from all five project sites were used as observations in the analysis and the results are presented in Table 5. Overall, it can be concluded that both the test section and test year have no significant influence on the MPD measurements. The interaction between the factor of test section and test year is not statistically significant either.

TABLE 5. ANOVA Table for Texture (MPD) Measurements

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Test Section (Control vs Keyhole)	3.06E-05	2	1.53E-05	0.0401	0.9608	3.3158
Test Year (2015 vs 2016)	5.87E-06	1	5.87E-06	0.0154	0.9022	4.1709
Interaction	1.58E-05	2	7.92E-06	0.0207	0.9795	3.3158
Within	0.0115	30	0.0004			
Total	0.0115	35				

Summary of Results

Based on the data analysis at each test site, a matrix was created to provide summary of results. Table 6 presents the summary result matrix for the five test sites. Summarized analysis of the five test sites are presented herein:

- **Lehman Causeway (Site 1) -** Identified as a rigid pavement with transverse grooved surface texture. The colored bike treatment is an epoxy modified green colored coating. The control and keyhole sections meet the minimum friction number requirement at DFT40 (FN of 40) for both years. However, overall friction decreased for year 2016 when compared to 2015 at the control and keyhole (on- and off-stripes) sections due to traffic effects. Overall average texture measurements across all sections indicate a decrease in MPD values in year 2016 when compared to 2015.

- **Julia Tuttle Causeway (Site 2) –** Is a dense graded friction course surface with an epoxy modified green colored coating treatment. The friction values for both years at the control and keyhole on-stripe sections meet the minimum requirement at DFT40. Friction values at the keyhole off-stripe was lower than normal ranges. No change in friction values was observed at the on-and off-stripe keyholes over the two year period, however there was a slight increase in friction from year 2015 to 2016 at the control section. The friction value at the control section is higher than at the keyhole off-stripe section. Overall average texture measurements across all sections indicate a slight decrease in MPD values in year 2016 when compared to 2015.

- **MacArthur Causeway Entrance and Exit Ramps (Site 3) –** Identified as a dense graded friction course surface with a thermoplastic green colored treatment. Friction values meet minimum requirements specified for DFT40 (FN of 40) for both years at the control and keyhole sections. Slight decrease in friction values was observed at the keyhole (on- and off-stripes) than the control sections over time due to traffic effects at both the entrance and exit ramps. Overall average texture measurements across all sections at the entrance ramp indicate a slight increase in MPD values in year 2016 when compared to 2015. However, at the exit ramp there was no change in surface texture over the two year period.

- **Pineda Causeway (Site 4) –** Identified as an open graded friction course surface with a high friction surface treatment (HFST) application for the green colored bike lane. Friction values meet the minimum requirements specified for DFT40 (FN of 40) at the control and keyhole on-stripe sections for both years. However, friction value on the keyhole off-stripe section was lower than normal ranges. Friction values decreased slightly over time at the keyhole on- and off-stripes compared to the control section due to traffic effects. Overall average texture measurements across all sections indicate a slight increase in MPD values in year 2016 when compared to 2015.

- **Rickenbacker Causeway (Site 5) –** Identified as an open graded friction course surface with an epoxy modified green colored coating treatment for the bike lane. Friction values meet the minimum requirements specified for DFT40 (FN of 40) at the control and keyhole sections for both years. Friction values decreased slightly in year 2016 when compared to year 2015 at the keyhole on-stripe. However, friction value at the off-stripe keyhole section slightly increased in 2016 compared to 2015. Overall average texture measurements across all sections indicate a decrease in MPD in year 2016 when compared to 2015.

TABLE 6. Results Matrix for the Five Test Locations for the Green Colored Bike Lanes

Test Location	Existing Surface Type	Type of Bike Lane Treatment	Average Friction, DFT (x100)						Average Texture, MPD (in)		Cumulative Traffic
			Control		Keyhole On-Stripe		Keyhole Off-Stripe				
			2015	2016	2015	2016	2015	2016	2015	2016	
Lehman Causeway	Rigid Pavement, Transverse Grooved	Epoxy Modified Coating	48	47	46	41	49	47	0.029	0.026	6,205,000
Julia Tuttle Causeway onto I-195	Dense Graded AC	Epoxy Modified Coating	51	55	46	46	32	32	0.017	0.016	6,205,000
MacArthur Causeway Entrance Ramp	Dense Graded AC	Thermoplastic	74	62	55	56	52	43	0.010	0.013	657,000
MacArthur Causeway Exit Ramp	Dense Graded AC	Thermoplastic	66	60	54	55	43	45	0.010	0.010	657,000
Pineda Causeway	Open Graded AC	High Friction Surface Treatment (HFST)	77	83	71	66	35	35	0.059	0.060	8,030,000
Rickenbacker Causeway	Open Graded AC	Epoxy Modified Coating	44	44	48	45	44	48	0.040	0.035	6,387,500

CONCLUSIONS

This study was aimed at evaluating the friction and surface texture characteristics of five selected green bike lane sites in Florida over a two year period. Based on the results, the following key findings and conclusions are drawn:

- All sections at the green bike lane sites met the initial friction number requirements for Florida's Patterned Textured Pavement Specification. Minor friction loss was observed at the keyhole sections especially the off-stripe when compared to the control sections indicating traffic wear effects.
- On average for each independent test site, friction values at the control sections was higher than the keyhole on-stripe sections.
- The green treatment material on the bike lane have minimal impact on the surface texture when applied to the existing pavement surface.
- Overall, yearly comparison of friction and texture results showed minimal to no change in the friction and MPD values between year 2015 and 2016, which indicates all bike lane sites maintained their friction and texture characteristics well after one year of traffic service.
- Two-way ANOVA analysis on friction measurements indicated no significant difference in friction measurements between year 2015 and 2016. However, the type of test section (which includes pavement surface type as well as type of green bike lane material applied and the presence of traffic wear) have significant influence on the friction measurements, which means that the friction measurements are affected by whether the section received green material and/or experienced traffic wear or not. The interaction between test section and year have no significant influence on the friction measurements.
- In terms of surface texture or Mean Profile Texture (MPD) measurements, the two-way ANOVA analysis indicated that both the test section and test year have no significant influence on the texture. The interaction between the factor of test section and test year was not statistically significant either.

FDOT will continue to monitor these projects to assess long term frictional and surface texture characteristics, distress performance, and safety on these colored bicycle lanes.

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APPENDIX A -2015 FRICTION AND TEXTURE MEASUREMENT RESULTS

Table 1. DFT Measurements at all Test Sites

Test Sites	Run#	Bike Lane Control Section			Bike Lane Keyhole On -Stripe			Existing Surface Keyhole Off - Stripe		
		Testing Speed, mph (km/h)			Testing Speed, mph (km/h)			Testing Speed, mph (km/h)		
		20 (30)	30 (50)	40 (65)	20 (30)	30 (50)	40 (65)	20 (30)	30 (50)	40 (65)
Site 1	1	0.56	0.533	0.543	0.396	0.357	0.345	0.478	0.486	0.492
	2	0.452	0.428	0.426	0.441	0.412	0.62	0.484	0.494	0.508
	3	0.496	0.47	0.471	0.444	0.425	0.423	0.447	0.461	0.475
	AVG	0.503	0.477	0.480	0.427	0.398	0.463	0.470	0.480	0.492
Site 2	1	0.602	0.537	0.522	0.507	0.471	0.45	0.332	0.318	0.314
	2	0.593	0.53	0.514	0.523	0.478	0.471	0.336	0.318	0.314
	3	0.551	0.496	0.484	0.512	0.474	0.459	0.345	0.329	0.322
	AVG	0.582	0.521	0.507	0.514	0.474	0.460	0.338	0.322	0.317
Site 3(a) Entrance Ramp	1	0.673	0.706	0.735	0.554	0.563	0.59	0.469	0.514	0.559
	2	0.719	0.756	0.788	0.513	0.522	0.533	0.41	0.464	0.512
	3	0.611	0.647	0.685	0.52	0.51	0.539	0.404	0.442	0.477
	AVG	0.668	0.703	0.736	0.529	0.532	0.554	0.428	0.473	0.516
Site 3(b) Exit Ramp	1	0.476	0.448	0.435	0.521	0.495	0.492	0.46	0.44	0.43
	2	0.476	0.46	0.454	0.51	0.497	0.495	0.463	0.443	0.439
	3	0.461	0.44	0.43	0.478	0.47	0.463	0.444	0.444	0.443
	AVG	0.471	0.449	0.440	0.503	0.487	0.483	0.456	0.442	0.437
Site 4	1	0.754	0.769	0.774	0.709	0.712	0.727	0.336	0.344	0.374
	2	0.771	0.766	0.775	0.715	0.71	0.718	0.305	0.327	0.341
	3	0.733	0.733	0.752	0.709	0.69	0.696	0.312	0.334	0.339
	AVG	0.753	0.756	0.767	0.711	0.704	0.714	0.318	0.335	0.351
Site 5	1	0.476	0.448	0.435	0.521	0.495	0.492	0.46	0.44	0.43
	2	0.476	0.46	0.454	0.51	0.497	0.495	0.463	0.443	0.439
	3	0.461	0.44	0.43	0.478	0.47	0.463	0.444	0.444	0.443
	AVG	0.471	0.449	0.440	0.503	0.487	0.483	0.456	0.442	0.437

Table 2. Surface Texture Measurements at all Test Sites

Test Sites	Run#	CTM, MPD (in.)		
		Bike Lane Control Test Section	Bike Lane Keyhole On-Stripe	Existing Surface Keyhole Off-Stripe
Site 1	1	0.024	0.056	0.035
	2	0.035	0.031	0.021
	3	0.030	0.013	0.019
	AVG	0.030	0.033	0.025
Site 2	1	0.019	0.011	0.016
	2	0.018	0.012	0.017
	3	0.026	0.013	0.018
	AVG	0.021	0.012	0.017
Site 3(a) Entrance Ramp	1	0.014	0.008	0.01
	2	0.009	0.009	0.01
	3	0.008	0.008	0.012
	AVG	0.010	0.008	0.011
Site 3(b) Exit Ramp	1	0.009	0.008	0.013
	2	0.008	0.008	0.011
	3	0.013	0.01	0.012
	AVG	0.010	0.009	0.012
Site 4	1	0.061	0.054	0.069
	2	0.052	0.056	0.071
	3	0.055	0.052	0.06
	AVG	0.056	0.054	0.067
Site 5	1	0.043	0.046	0.041
	2	0.044	0.05	0.026
	3	0.038	0.042	0.027
	AVG	0.042	0.046	0.031

APPENDIX B -2016 FRICTION AND TEXTURE MEASUREMENT RESULTS

Table 3. DFT Measurements at all Test Sites

Test Sites	Run#	Bike Lane Control Section Testing Speed, mph (km/h)			Bike Lane Keyhole On -Stripe Testing Speed, mph (km/h)			Existing Surface Keyhole Off -Stripe Testing Speed, mph (km/h)		
		20 (30)	30 (50)	40 (65)	20 (30)	30 (50)	40 (65)	20 (30)	30 (50)	40 (65)
Site 1	1	0.528	0.493	0.465	0.503	0.451	0.436	0.537	0.529	0.524
	2	0.539	0.494	0.473	0.493	0.445	0.415	0.442	0.439	0.439
	3	0.549	0.506	0.484	0.461	0.428	0.393	0.478	0.443	0.437
	AVG	0.539	0.497	0.474	0.485	0.441	0.415	0.486	0.470	0.467
Site 2	1	0.5787	0.5325	0.5102	0.499	0.478	0.474	0.321	0.313	0.312
	2	0.5967	0.601	0.6125	0.508	0.477	0.461	0.364	0.355	0.352
	3	0.5867	0.5443	0.5313	0.494	0.462	0.456	0.313	0.310	0.309
	AVG	0.587	0.559	0.551	0.500	0.472	0.463	0.332	0.326	0.324
Site 3(a) Entrance Ramp	1	0.613	0.602	0.611	0.526	0.529	0.548	0.312	0.325	0.335
	2	0.601	0.597	0.616	0.524	0.533	0.543	0.396	0.407	0.422
	3	0.612	0.618	0.640	0.542	0.545	0.578	0.513	0.523	0.541
	AVG	0.609	0.606	0.622	0.531	0.535	0.556	0.407	0.418	0.433
Site 3(b) Exit Ramp	1	0.639	0.599	0.583	0.589	0.569	0.573	0.428	0.430	0.438
	2	0.632	0.607	0.607	0.571	0.552	0.541	0.428	0.429	0.436
	3	0.630	0.613	0.617	0.570	0.540	0.545	0.465	0.467	0.478
	AVG	0.634	0.606	0.602	0.576	0.553	0.553	0.440	0.442	0.451
Site 4	1	0.773	0.789	0.811	0.696	0.688	0.701	0.319	0.329	0.332
	2	0.768	0.799	0.823	0.657	0.637	0.651	0.367	0.360	0.365
	3	0.830	0.842	0.863	0.639	0.629	0.624	0.339	0.326	0.344
	AVG	0.790	0.810	0.832	0.664	0.651	0.659	0.341	0.338	0.347
Site 5	1	0.471	0.453	0.445	0.473	0.464	0.451	0.453	0.476	0.458
	2	0.468	0.448	0.445	0.454	0.435	0.446	0.457	0.467	0.478
	3	0.447	0.433	0.430	0.443	0.435	0.439	0.483	0.488	0.507
	AVG	0.462	0.445	0.440	0.457	0.445	0.445	0.464	0.477	0.481

Table 4. Surface Texture Measurements at all Test Sites

Test Sites	Run#	CTM, MPD (in.)		
		Bike Lane Control Test Section	**Bike Lane Keyhole On-Stripe**	**Existing Surface Keyhole Off-Stripe**
Site 1	1	0.038	0.015	0.030
	2	0.032	0.018	0.016
	3	0.028	0.029	0.032
	AVG	0.033	0.020	0.026
Site 2	1	0.020	0.010	0.015
	2	0.023	0.012	0.017
	3	0.023	0.009	0.015
	AVG	0.022	0.010	0.016
Site 3(a) Entrance Ramp	1	0.010	0.010	0.017
	2	0.010	0.009	0.017
	3	0.010	0.017	0.015
	AVG	0.010	0.012	0.016
Site 3(b) Exit Ramp	1	0.012	0.1900	0.014
	2	0.010	0.2000	0.011
	3	0.012	0.1700	0.010
	AVG	0.011	0.187	0.012
Site 4	1	0.052	0.060	0.068
	2	0.063	0.053	0.070
	3	0.060	0.052	0.064
	AVG	0.058	0.055	0.067
Site 5	1	0.029	0.040	0.037
	2	0.036	0.043	0.028
	3	0.034	0.044	0.025
	AVG	0.033	0.042	0.030