State of Florida

Department of Transportation

EVALUATION OF WARM-MIX ASPHALT (WMA) PERFORMANCE IN FLORIDA

FDOT Office
State Materials Office

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1 EXECUTIVE SUMMARY

Economics and environmental issues have spurred the introduction of the Warm Mix Asphalt (WMA) technology in the pavement construction industry. The Florida Department of Transportation (FDOT) started using the WMA technology in 2006 based on reported benefits due to lower asphalt mixing and compaction temperatures. Limited field and laboratory studies have indicated that WMA may have similar performance as traditional Hot Mix Asphalt (HMA). However, some studies have also suggested that the use of WMA may increase long-term rutting and stripping potential and hence the long-term performance evaluation of the WMA mixtures is still warranted. With the primary objective of obtaining long-term field performance data of Florida's WMA, the respective field performance of six representative WMA projects using five different technologies (one additive and four water foaming technologies) was monitored and documented in this report. The performance of the WMA projects was then compared to the historical performance data of Florida's asphalt pavements. The results to date indicate that WMA performance is comparable to that of HMA. These projects will continue to be monitored to further assess their long-term field performance.

2 INTRODUCTION

As implied by its name, Warm Mix Asphalt (WMA) allows significant lowering (50 °F to 100 °F lower) of the production and paving temperatures when compared to the conventional Hot Mix Asphalt (HMA). The reduced production temperature of the WMA promises various benefits over HMA including better workability and compaction, reduced energy consumption, reduced worker exposure to asphalt fumes, and lower greenhouse gas emissions (*1*).

Owing to the potential advantages of the WMA mentioned above, a total of 46 million tons of WMA were produced throughout the United States in 2010, a 254 percent increase from 13 million tons in 2009 which clearly reflects the rapid adoption of the WMA technologies nationwide (*2*). To this end, the Florida Department of Transportation (FDOT) constructed its first WMA pavement in 2006. In 2010, FDOT's standard specifications were modified to allow the use of WMA for all asphalt mixture types (*3*). This report documents the WMA technologies used on FDOT projects, and reports on six selected WMA projects and their field performance to date.

3 OBJECTIVE AND SCOPE

The objective of this study is to provide a summary on Florida's experience with various WMA technologies and report on WMA field performance to date. Six WMA projects were selected based on WMA technology type, WMA quantity placed, pavement age, and availability of HMA control sections. Construction quality control data and annual pavement condition ratings in terms of cracking, rutting, and smoothness were used to evaluate construction quality and pavement performance, respectively. These projects will continue to be monitored annually for long-term performance.

4 WARM MIX ASPHALT OVERVIEW

4.1 Warm Mix Asphalt Technologies

The WMA technologies currently used by the asphalt paving industry can be divided into three major categories depending on the additives used for the process: 1) water additives, 2) chemical additives, and 3) organic additives. Water additives have been the most widely used WMA technologies on FDOT projects followed by chemical additives. To date, the WMA technology using organic additives has not been used on FDOT projects. The following is a brief summary on each of the WMA technologies listed above.

4.1.1 Water Additives

Direct and indirect methods are used to introduce water into the asphalt binder during mixing at the plant to create a foaming effect. When the cold water contacts the hot asphalt binder, the water turns to steam and the volume of the asphalt binder is increased. The viscosity of the asphalt binder is reduced until the mixture has cooled. The amount of volume expansion relies on the quantity of water added and the temperature of asphalt binder (*4*).

The direct method of foaming injects a small amount of water to hot asphalt binder with a foaming nozzle. This method results in a temporary but large increase in the asphalt binder volume that enhances the coating potential of the asphalt binder at lower temperatures. The indirect foaming technique involves “water carrying chemical” additives or hydrophilic minerals as the source of foaming water.

4.1.2 Chemical Additives

Chemical additives do not change the asphalt binder viscosity. Rather, these surface-active agents (i.e. surfactants) reduce the frictional forces at the aggregate/binder interface enabling the production and compaction of mixtures at a lower temperature.

4.1.3 Organic Additives

Organic additives typically include waxes with melting points below a normal HMA production temperature. These organic additives decrease the viscosity of asphalt binder above their melting point. The organic additive should be carefully selected so that the melting point of the additive is higher than the expected in-service temperature of the pavement to minimize permanent deformation and to prevent the asphalt mixture from becoming brittle at lower temperatures.

4.1.4 WMA Benefits and Concerns

A number of potential benefits have been associated with WMA as mentioned previously. The reported benefits include increased worker safety, lower fuel and energy consumption of 20 to 30 percent, improved mixture workability, and reduced emissions. Asphalt fumes and aerosols have been reported to be reduced by 30 to 50 percent while reductions reported for carbon dioxide (CO_2) and sulfur dioxide (SO_2) have been in the range of 30 to 40 percent (*1*). Reductions of 10 to 30 percent of carbon monoxide (CO) and 20 to 25 percent of dust have also been reported. Figure 1a shows fumes and dust released from an asphalt mixture at normal HMA mixing temperatures while fumes are not visible from a WMA mixture in Figure 1b. Other WMA advantages include the potential for an extended paving season, longer haul distances, improved compaction, and the ability to use higher proportions of reclaimed asphalt pavement (RAP) due to reduced asphalt binder viscosities (*5*). Also, the reduction in asphalt binder aging due to the lower production temperatures may offset the effect of aged RAP binder.

(a) Hot-Mix Asphalt (HMA) at 320 °F (b) Warm-Mix Asphalt (WMA) at 250 °F

Figure 1. Fumes and dust from HMA vs. WMA

However, several potential concerns associated with the use of WMA have also been reported. These concerns include: 1) incomplete drying of the aggregate, particularly highly absorptive aggregate such as limestone typically used in Florida, 2) potential for increased moisture susceptibility due to the use of water during the foaming process, 3) premature rutting due to the lower asphalt binder viscosity of WMA, 4) unknown effects of chemical additives on the long-term performance of the asphalt binder, 5) concerns with the inability of WMA to provide sufficient radiant energy to heat the RAP, and 6) a lack of overall long-term performance information. Several studies have indicated that WMA has comparable or better performance compared to HMA (*1*, *6*, *7*, *8*, *9*, *10*). However, most studies have been limited to short-term field tests or laboratory evaluations.

5 FLORIDA'S WMA EXPERIENCE

5.1 Summary of Projects

Between 2006 and 2012, FDOT has used 833,980 tons of WMA on 77 WMA projects and seven different WMA technologies. Figure 2 shows FDOT's WMA production through 2012. As a reference, FDOT's total resurfacing program accounts for approximately 3 million tons of HMA each year. Table 1 summarizes the different WMA technologies used on FDOT projects. As can be seen from the table, the foaming process was the predominant technology in Florida and was used for almost 95 percent of the total WMA projects.

Six WMA projects were selected for preliminary evaluation based on mixture type, pavement age, type of WMA technology used, and total tonnage of WMA mixes produced. Table 2 provides information for the six projects selected for the study. With the exception of US-90 in Baker County, all selected WMA projects were constructed with comparable HMA control sections.

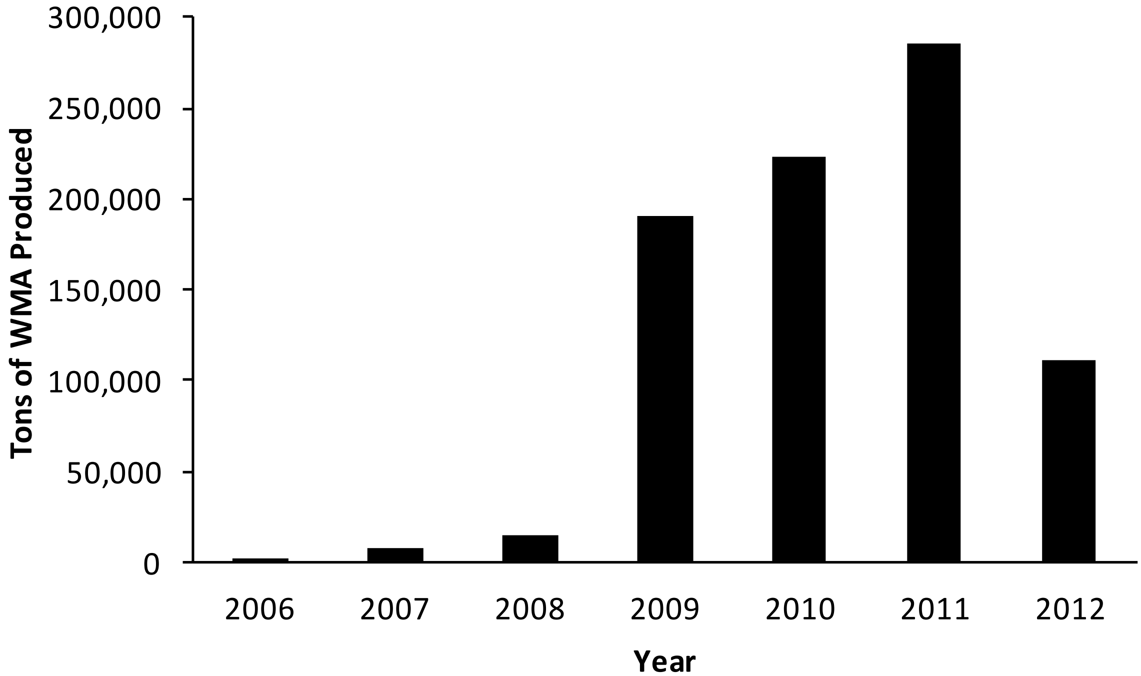


Figure 2. FDOT's WMA production

Table 1. WMA Technologies Used on FDOT Projects

WMA Technology	Process Type	Production Temperature at Plant (°F)	Number of Projects	Total Tonnage Produced to Date
Astec DBG	Direct Foaming	260 – 285	45	508,516
Meeker	Direct Foaming	265 – 300	14	227,296
Terex	Direct Foaming	270 – 275	10	74,358
Evotherm DAT	Chemical Additive	250 – 270	4	16,203
Gencor	Direct Foaming	260	2	5,120
Eco-Foam II	Direct Foaming	270	1	1,758
Aspha-Min	Indirect Foaming	270	1	730

Table 2. WMA Projects Selected for Evaluation

Project Number	County	Route	Mix Type	Mainline Tons Placed	Process Type	WMA Technology	Date Placed
1	Seminole	SR-417	FC-5	730	Indirect Foaming	Aspha-Min	3/2006
2	Polk	US-92	SP-12.5	1,883	Chemical Additive	Evotherm	10/2007
3	Flagler	SR-11	SP-12.5	5,973	Direct Foaming	Astec DBG	12/2007
4	Collier	I-75	FC-5	54,873	Direct Foaming	Meeker	10/2009
5	Seminole	SR-15	FC-9.5	1,770	Direct Foaming	Gencor	12/2009
6	Baker	US-90	FC-5/ SP-12.5	64,089	Direct Foaming	Astec DBG	3/2011

5.2 Pavement Performance Evaluation

The performance of the WMA projects was evaluated using FDOT's annual Pavement Condition Survey (PCS) data. FDOT's PCS data includes the ratings of a pavement in terms of crack, ride, and rut. All 3 ratings are evaluated on a scale of 0.0 to 10.0, where a rating of 10.0 is equivalent to a pavement with no distress. Figure 3 shows the relationship between the PCS rating scale and the amount of cracks, ride number, and rut depth. Also shown in the figure is the deficiency threshold of 6.5 below which a pavement is considered to have failed. The pavement becomes due for resurfacing when any of the three ratings falls below this threshold. Although FDOT has historically used the ride rating which is obtained from the Ride Number (RN) for both ride acceptance and pavement management, implementation efforts are underway for adopting the use of International Roughness Index (IRI) for ride acceptance. Nonetheless, the ride rating (or

RN) will still be used for pavement management purposes. The ride quality of the WMA projects is presented using both the International Roughness Index (IRI) and Ride Number (RN) in this report.

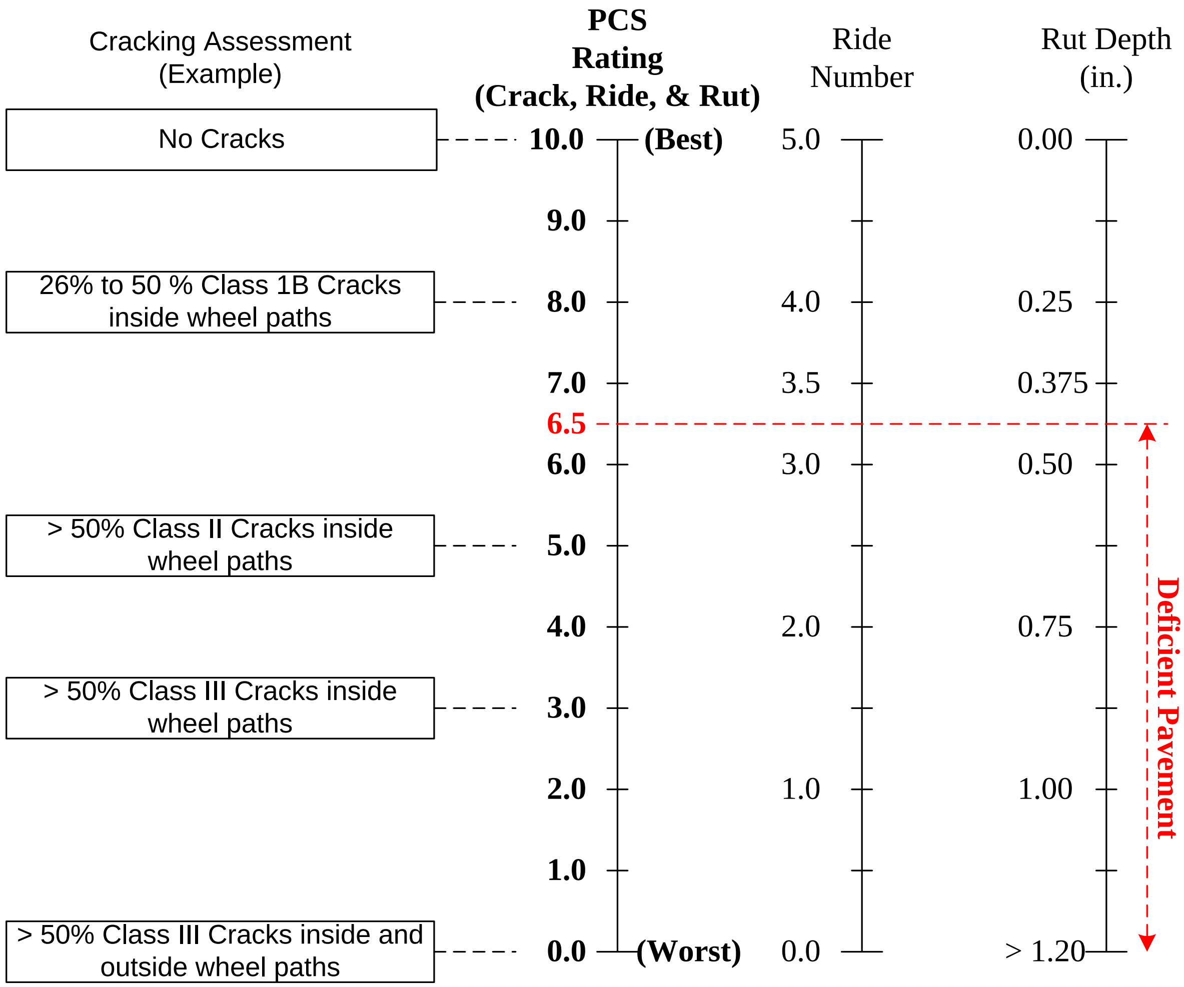
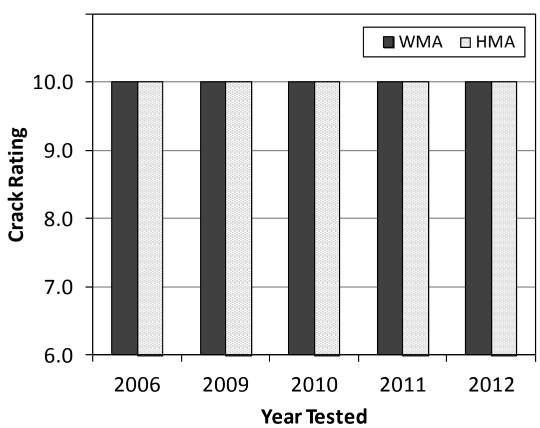


Figure 3. PCS Rating vs Amount of Cracks, Ride Number, and Rut Depth

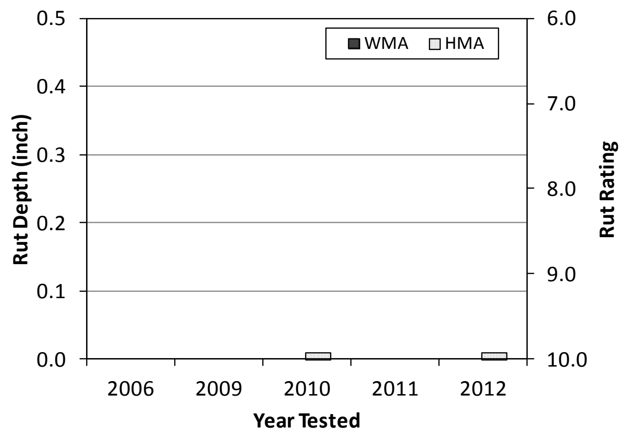
5.3 Project 1: SR-417 in Seminole County

In March 2006, FDOT's first WMA project was constructed on SR-417 near Orlando, FL. The WMA used on this project was a 0.75-inch thick FC-5 Open-Graded Friction Course (OGFC) with a PG 76-22 polymer-modified asphalt binder. The Aspha-Min indirect-foaming additive was pumped into the asphalt drum at a rate of 6 pounds per ton to produce the WMA (*3*). A comparable HMA section with the same FC-5 characteristics as the WMA was also paved within the project limits. The mixing and compacting temperatures for the WMA and HMA were 270°F and 320°F, respectively.

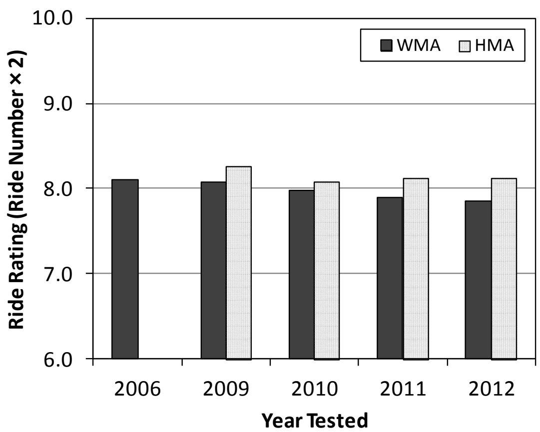
Figure 4 shows the performance history of the WMA and HMA mixtures to date. Both the WMA and HMA mixtures are still in good condition after 6 years of service with no significant performance differences.



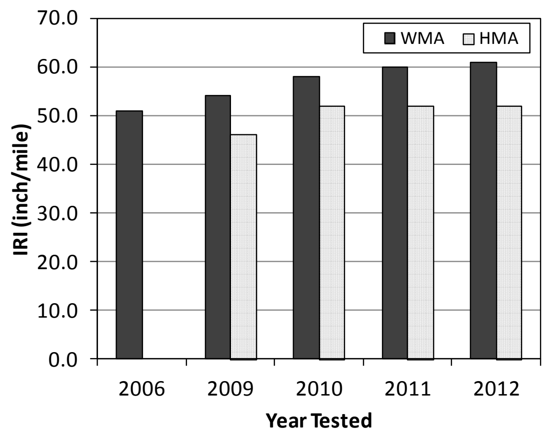
(a) Crack Rating



(b) Rut Rating



(c) Ride Rating



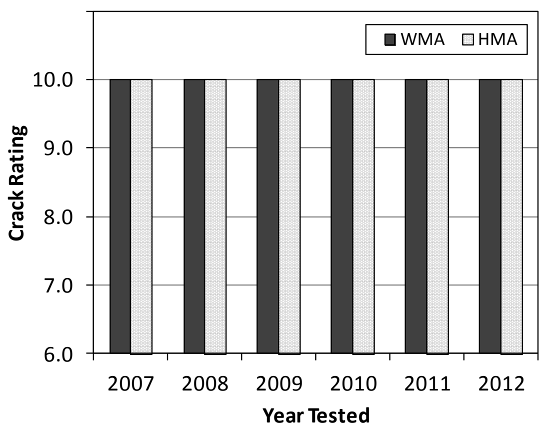
(d) IRI

Figure 4. Performance history of SR 417 in Seminole County

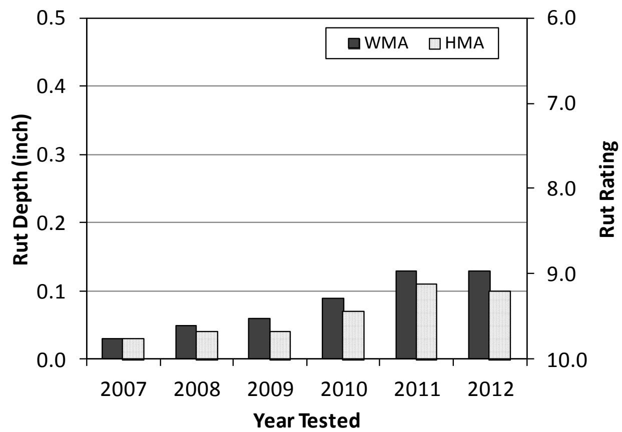
5.4 Project 2: US-92 in Polk County

FDOT's second WMA project was constructed on US-92 near Lakeland, FL, in October 2007. Both the WMA and HMA were used to construct a 1.5-inch thick 12.5-mm Superpave structural mixture with 15 percent Recycled Asphalt Pavement (RAP) and PG 76-22 polymer-modified asphalt binder. Evotherm DAT which is a chemical additive was used at a rate of 5 percent by weight to produce the WMA (3). A conventional HMA FC-5 mixture was placed on top of both the WMA and HMA structural mixtures. The mixing and compacting temperatures of the WMA mixture were 250 °F and 230 °F, while those of HMA were 325 °F and 315 °F, respectively.

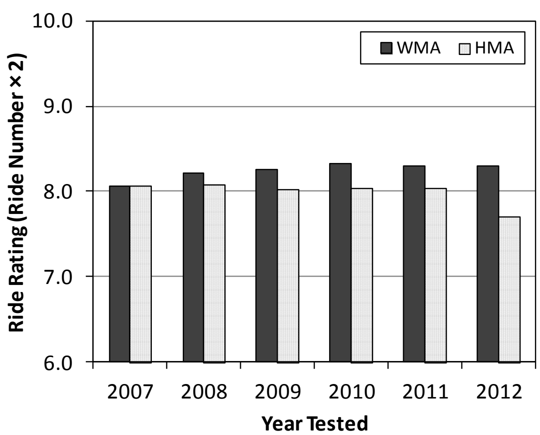
Figure 5 shows the performance histories of both the WMA and HMA mixtures. No significant performance difference was observed between WMA and HMA sections.



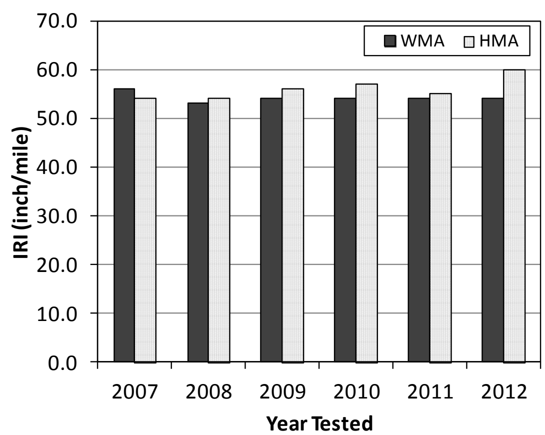
(a) Crack Rating



(b) Rut Rating



(c) Ride Rating



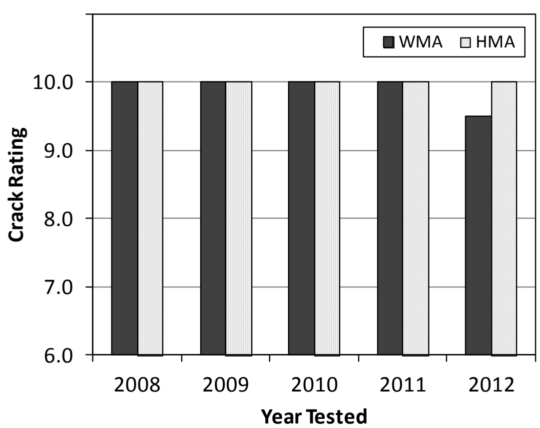
(d) IRI

Figure 5. PCS history for US 92, Polk County

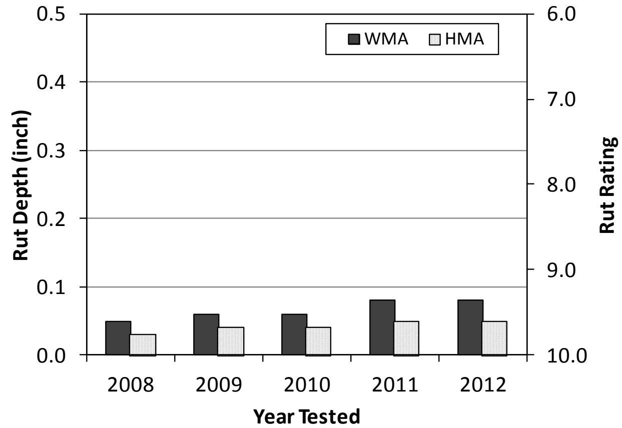
5.5 Project 3: SR-11 in Flagler County

SR-11 in Flagler County was constructed using both the WMA and HMA technologies in December 2007. The WMA was used on a 1.5-inch thick SP-12.5 structural mixture with 45% fractionated RAP and RA-800 asphalt binder. The Astec Double Barrel Green (DBG) foaming method was used to inject water into the binder supply line at a rate of 2% by weight to produce the WMA. A conventional dense-graded HMA FC-12.5 mixture was placed over both WMA and HMA structural mixtures. The mixing and compacting temperatures of WMA mixture were 270 °F and 260 °F, while those of HMA were 310 °F and 300 °F, respectively.

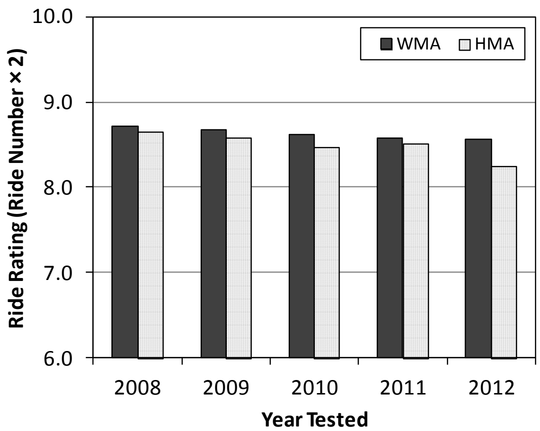
Figure 6 shows the performance histories for both the WMA and HMA mixtures. The figure shows that the WMA mixture is showing higher rutting and better ride when compared to the HMA but these differences are considered negligible. Nonetheless, the WMA section has started to show some minor cracking after 5 years of service whereas the HMA section is still free of cracks.



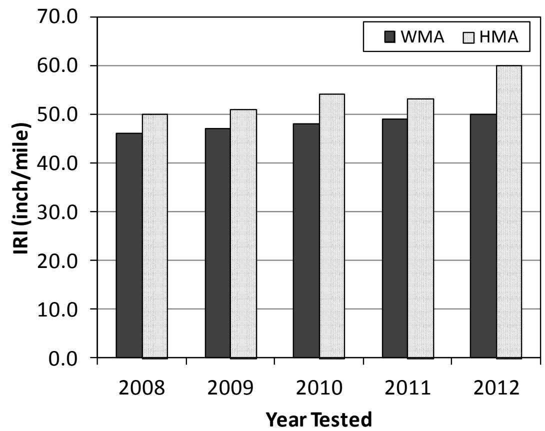
(a) Crack Rating



(b) Rut Rating



(c) Ride Rating

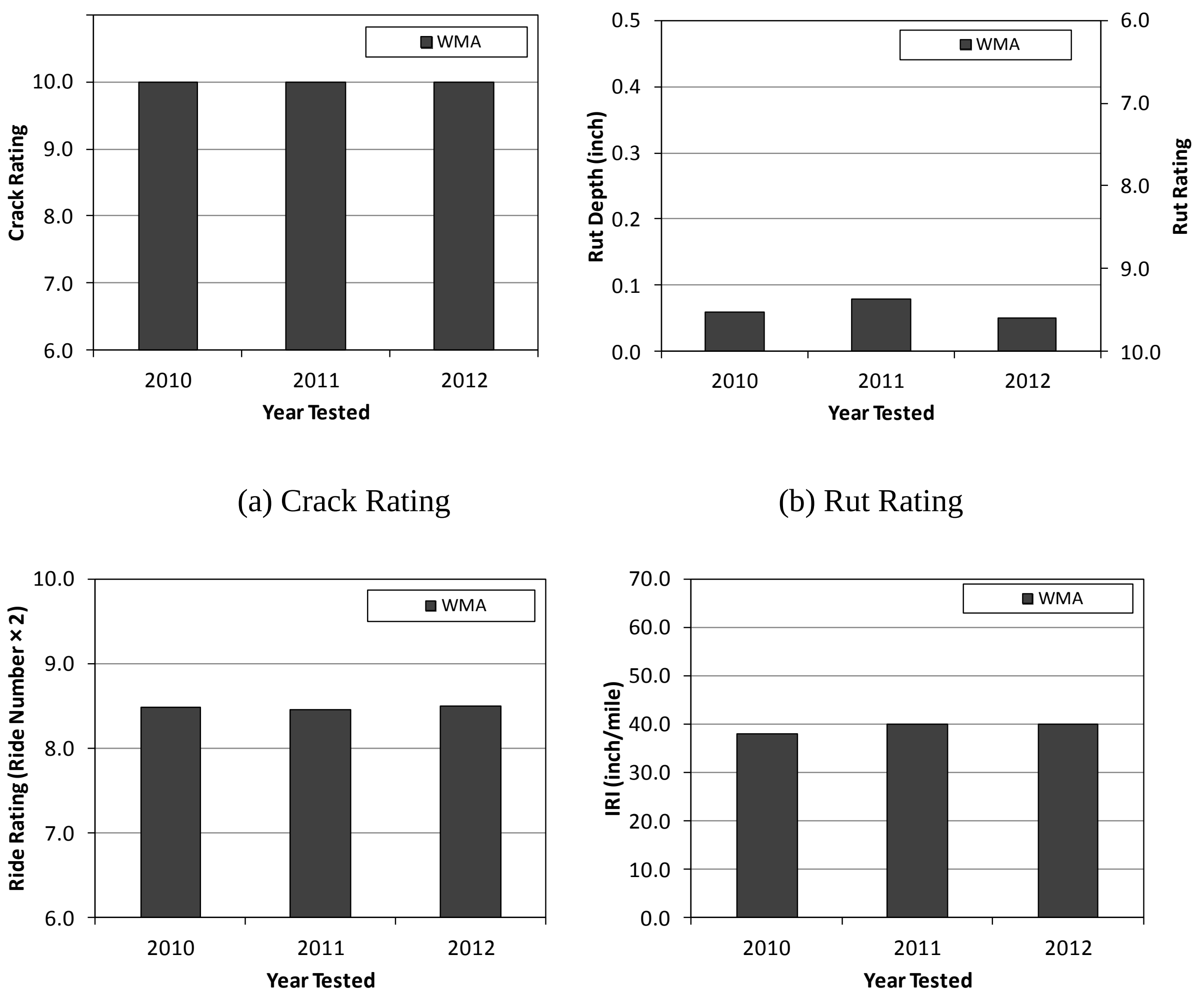


(d) IRI

Figure 6. PCS history for SR 11, Flagler County

5.6 Project 4: I-75 in Collier County

The northbound corridor of I-75 between Fort Myers and Naples was resurfaced in December, 2009. The WMA technology was used to pave the 0.75-inch thick FC-5 OGFC mixture. The Meeker direct-foaming process was used to inject water into the polymer-modified PG 76-22 asphalt binder which was used in the outside and middle lanes. The mixing and compacting temperatures of the WMA mixture were 275 °F and 270 °F respectively, nearly 50 to 60 °F lower than those of a typical HMA. A HMA section was also constructed in the northbound outside lane. Since PCS data was only collected in the middle lane, the performance data for the HMA section is not available. Figure 7 shows that after 3 years of service, the WMA mixture is still performing well.



(a) Crack Rating (b) Rut Rating

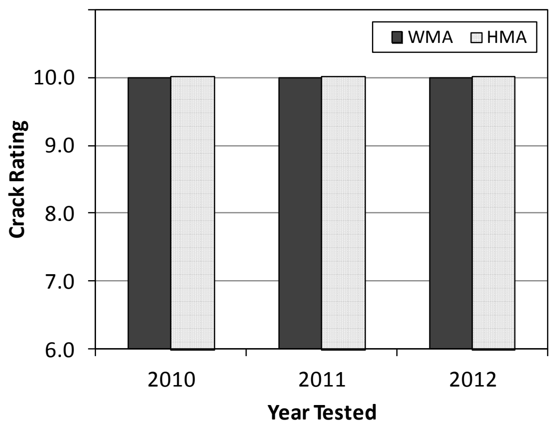
(c) Ride Rating (d) IRI

Figure 7. PCS history for I-75, Collier County

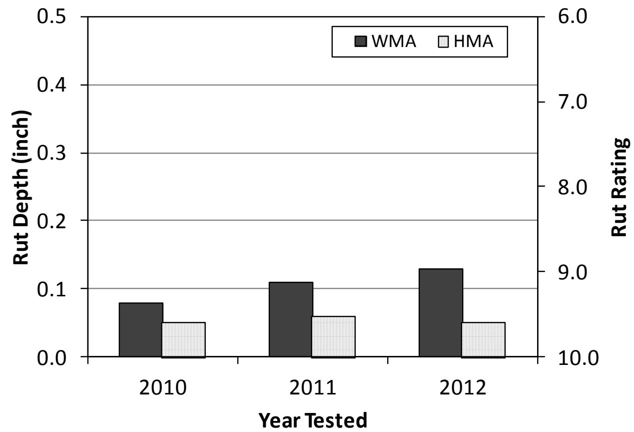
5.7 Project 5: SR-15 in Seminole County

SR-15 located north of Orlando, FL was constructed in December, 2009. It consisted of a 1.5-inch 12.5 mm Superpave structural layer and a 1.0-inch FC-9.5 friction course. The structural course was paved using the HMA technology throughout the project while the friction course included both WMA and HMA technologies. The Gencor process was used to produce the WMA mixture by injecting 1.25% to 2% water by weight of asphalt to create a foaming effect. The mixing and compacting temperatures of the WMA were both 260 °F and those of HMA were 315 °F and 310 °F, respectively.

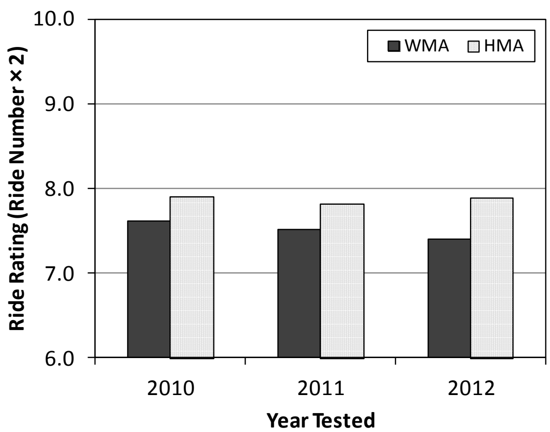
Figure 8 shows the performance histories of both the WMA and HMA mixtures to date. Although both the WMA and HMA sections are free of cracks, the WMA section started to show higher rutting than the HMA section. It is also noted that both the WMA and HMA sections are showing relatively lower ride quality for a 3-year old pavement, as indicated by the decreased RN and increased IRI in Figure 8.



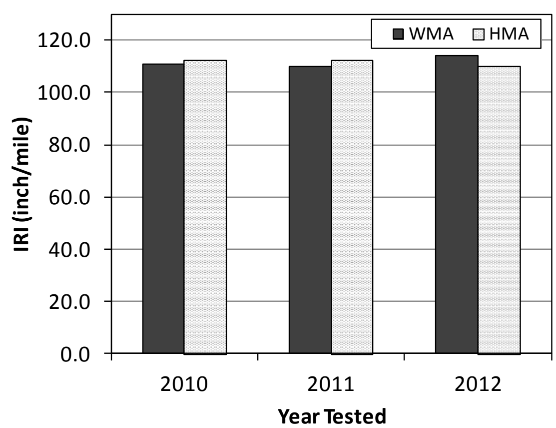
(a) Crack Rating



(b) Rut Rating



(c) Ride Rating



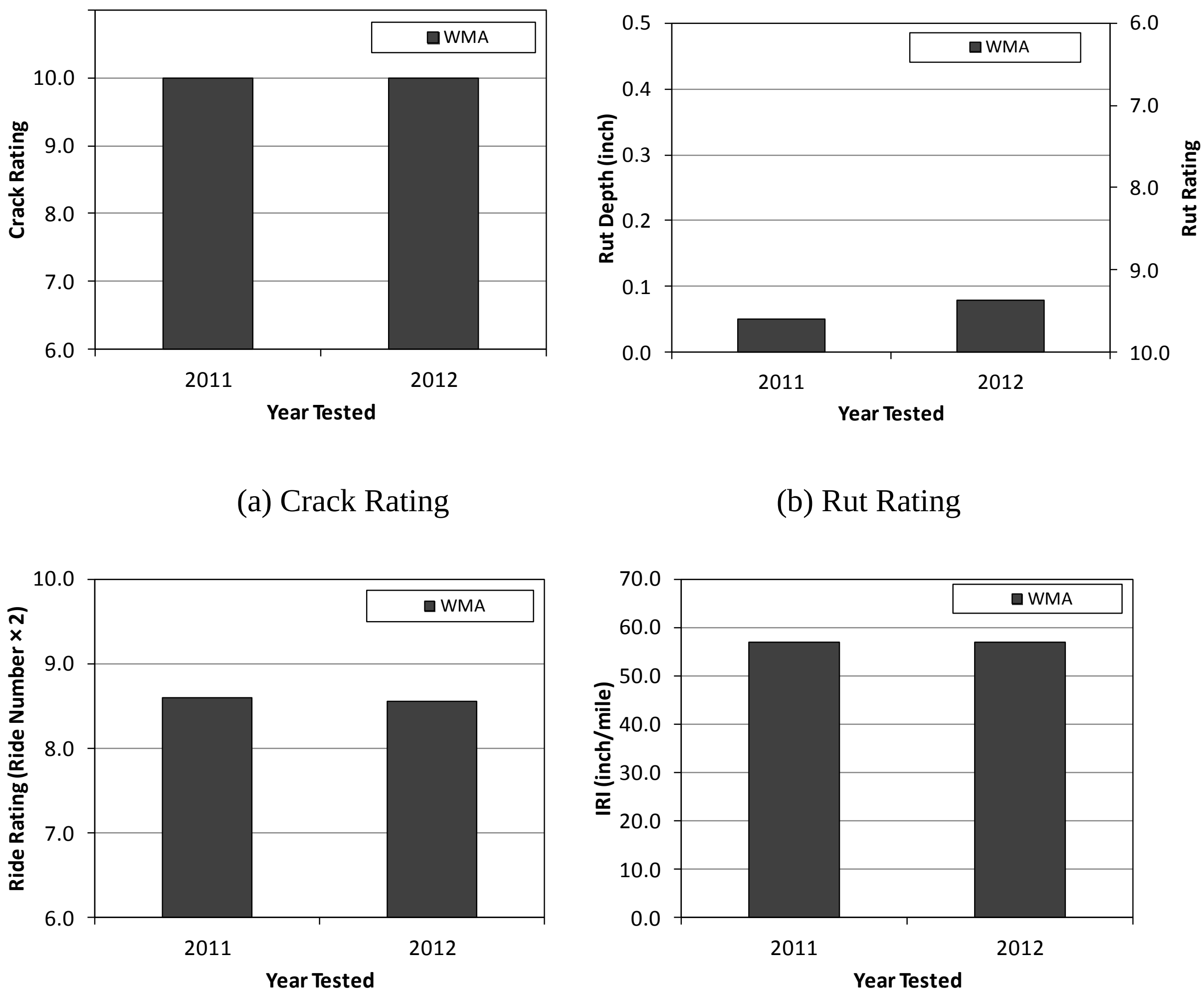
(d) IRI

Figure 8. PCS history for SR 15, Seminole County

5.8 Project 6: US-90 in Baker County

US-90 near Lake City, FL was constructed in March, 2010 with a 1.5-inch thick 12.5 mm Superpave structural course and a 1.5-inch thick FC-12.5 friction course, both of which included a PG 76-22 polymer modified asphalt binder. The Astec DBG technology was used on both lifts to produce the WMA. The mixing and compacting temperatures of the WMA were both 270 °F.

As the WMA technology was used throughout the limits of the project, an equivalent HMA counterpart is not available for this roadway. Figure 9 shows the WMA performance history to date which does not indicate any significant deficiencies to be noted.

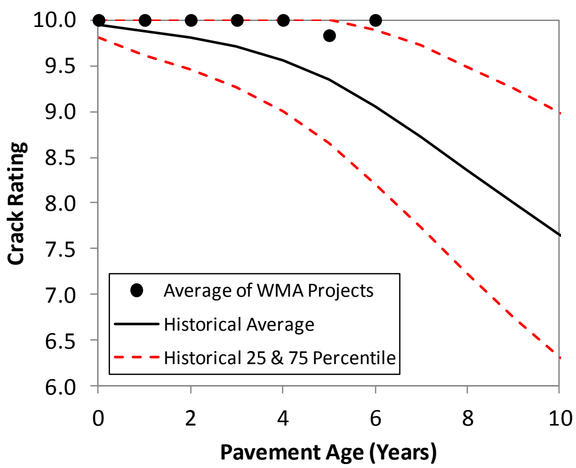


(c) Ride Rating (d) IRI

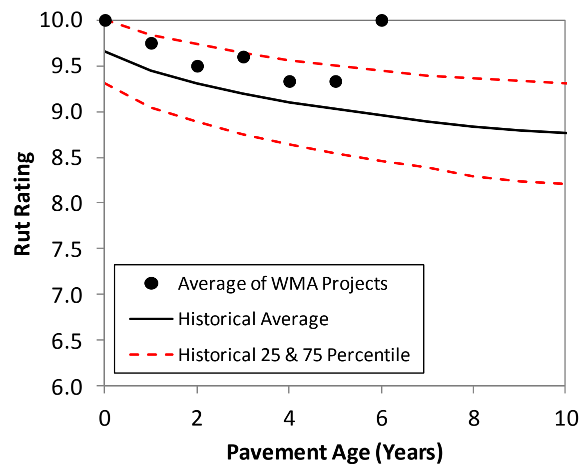
Figure 9. PCS history for US-90, Baker County

5.9 Comparison of WMA Performance with Historical PCS data

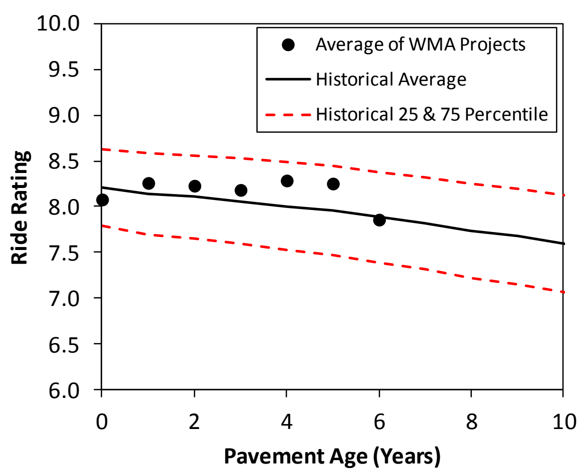
The average performance of six selected WMA projects presented above was compared to the historical performance of all FDOT asphalt projects which include all HMA projects over the last 35 years and WMA projects since 2006. It should be noted that the above six WMA projects represent five different WMA technologies used in Florida to date. Figure 10 shows the resulting PCS ratings (crack, ride, and rut) of the WMA along with the historical averages. For reference purposes, the 25 and 75 percentiles (i.e., lower and upper quartiles) of the historical data are also shown in the figure. As mentioned previously, FDOT has historically used the ride rating (based on RN) for both the ride acceptance and pavement management and hence, the IRI data is not available for the historical PCS data. It should also be noted that the crack and rut rating values of 10.0 plotted for the WMA projects at pavement age 6 is only based on FDOT's very first WMA project (Project Number 1) and may not be representative of the overall WMA performance. Nonetheless, even after neglecting these data points from the figure, the results shown in Figure 10 still indicate that on average, the performance of WMA is comparable to those of HMA which confirms what has been reported in the literature.



(a) Crack Rating



(b) Rut Rating



(c) Ride Rating

Figure 10. Comparison of WMA performance to historical HMA performance

5.10 Summary

Six FDOT projects were selected to evaluate the relative performance of WMA compared to that of HMA. A review of historical PCS data shows that on average WMA demonstrated good performance comparable to that of HMA. It must also be noted that the six WMA projects are 2 to 6 years old. Therefore, these WMA projects will continue to be monitored to characterize their long-term durability and performance.

6 CONCLUSIONS AND RECOMMENDATIONS

With the primary objective of assessing the long-term performance of WMA, the field performance of six representative WMA projects using five different technologies was compared to that of HMA. Following is a summary of findings:

- Based on the projects evaluated in this study, the field performance of Florida's WMA projects (to date) appears to be comparable to that of HMA, which is in agreement with the findings of other reported studies.
- There is no significant deterioration or poor performance identified in the six WMA projects evaluated to date.
- There is no practical difference in performance among the different WMA technologies used in the projects evaluated.

Although the field performance of WMA projects looks promising, it should be noted that the oldest WMA project evaluated in this study is only 6 years old, as of this writing. Therefore, it is understood that the field experience and the conclusion on the long-term performance of the WMA technologies are still limited. The projects evaluated in this project as well as other WMA projects will continue to be monitored.

7 ACKNOWLEDGEMENTS

The work represented herein was the result of a team effort. The authors would like to acknowledge FDOT's Pavement Condition Survey group for their diligent efforts and contributing knowledge.

8 DISCLAIMER

The content of this report reflects the views of the authors who are solely responsible for the facts and accuracy of the data as well as for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Florida Department of Transportation. This report does not constitute a standard, specification, or regulation. In addition, the above listed agency assumes no liability for its contents or use thereof.

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