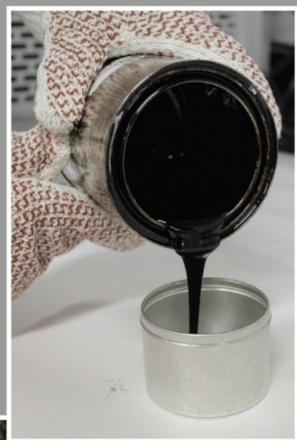
NCAT Report 14-02



LIFE-CYCLE ASSESSMENT OF 2012 NCAT PAVEMENT TEST TRACK GREEN GROUP MIXTURES

By
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March 2014

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ACKNOWLEDGEMENTS

This project was sponsored by part of the 2012 National Center for Asphalt Technology's Pavement Test Track. The project team appreciates and thanks the Alabama Department of Transportation, Alabama Department of Environmental Management, South Carolina Department of Transportation, and North Carolina Department of Transportation.

DISCLAIMER

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

1.1 Background

The concept of sustainability, while nothing new, has become a recent focus in the pavement community. Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (1).

The three components of sustainability, commonly referred to as the triple-bottom line, include economic growth, environmental protection, and social equity (2) (Figure 1). It is suggested that all three concepts should be considered and implemented when encouraging true sustainability (2, 3, 4). Table 1 provides examples of considerations under each of the triple-bottom line concepts.

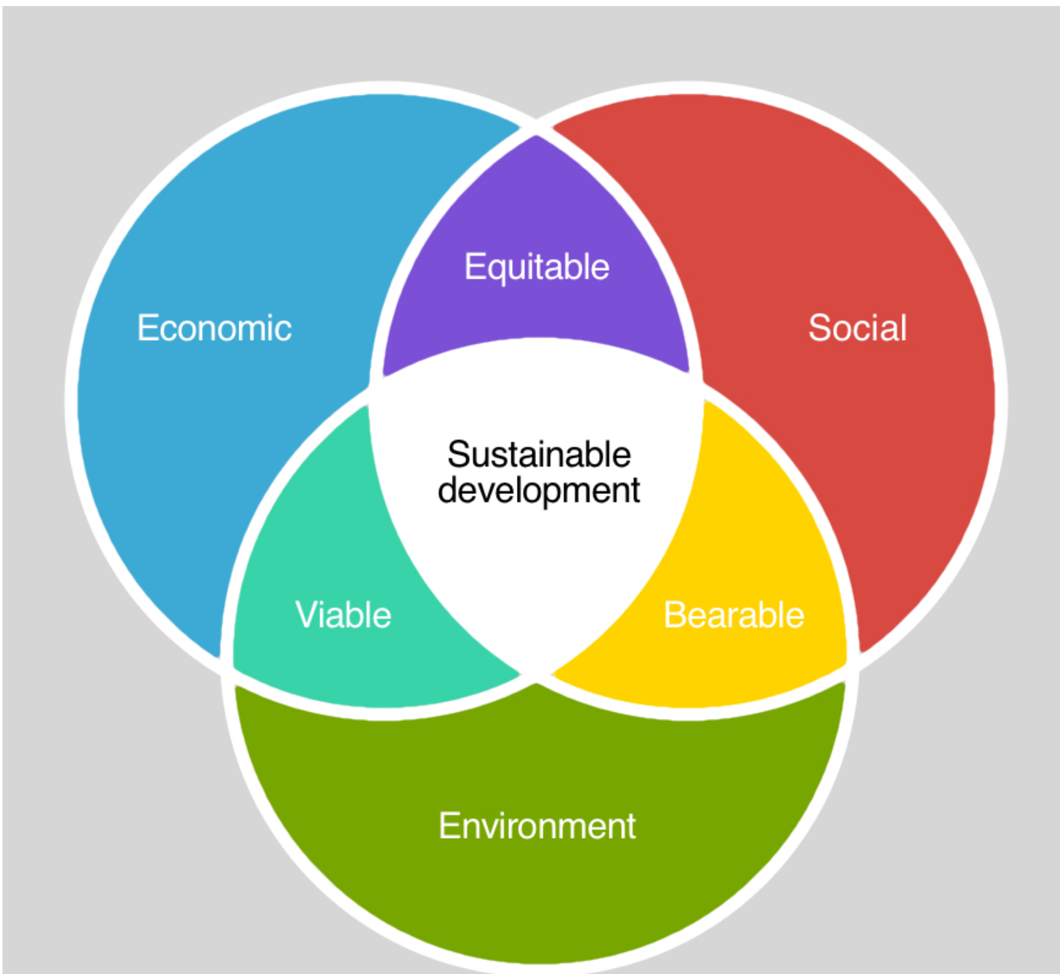

FIGURE 1 Triple-Bottom Line of Sustainability

TABLE 1 Examples of Triple-Bottom Line Considerations

Economic Growth	Environmental Protection	Social Equity
• Affordability • Resource efficiency • Cost internalization • Trade and business activity • Employment • Productivity • Tax burden	• Pollution prevention • Climate protection • Biodiversity • Precautionary action • Avoidance of irreversibility • Habitat preservation • Aesthetics	• Equity • Human health • Education • Community • Quality of life • Public participation

Multiple tools are required to fully quantify all three of the triple-bottom line concepts. Currently, life-cycle cost analyses (LCCA) are the most common tool which could be used in sustainability assessment. A LCCA is commonly used to quantitatively assess the financial viability of pavement choices. In terms of social benefits, there are currently few viable options for quantifying how pavements affect social equity.

The final triple-bottom line concept, environmental protection, uses life-cycle assessment (LCA) programs to quantify the environmental impacts by pavements. In effect, these tools are used to determine the carbon footprint (Carbon Dioxide equivalent, CO_2e), energy consumption, material consumption, and material contribution of a pavement. LCA programs only focus on quantifying environmental benefits or repercussions of construction choices.

When completing a LCA, five common phases of life can be considered: materials, construction and production, use, maintenance and rehabilitation, and end-of-life. Table 2 presents examples of phenomenon that can contribute to energy consumption and emissions for each phase of a pavement's life.

TABLE 2 Life-Cycle Assessment Contributors for Asphalt & Concrete Pavements (5)

Materials	Production and Construction	Use	Maintenance and Rehabilitation	End-of-Life
• Use of reclaimed asphalt pavement • Use of reclaimed asphalt shingles • Use of ground tire rubber • Use of fly ash • Use of blast furnace slag • Use of asphalt extenders • Biobinder	• Two-layer paving • Use of local materials to limit haul distance • Warm-mix asphalt (WMA) technologies • Self-consolidating concrete	• Lighting of streets • Leachate • Ride quality • Noise	• Traffic delay • Extraction • Production • Placement • Traffic control • Detours	• Traffic delay • Salvage • Transport

1.2 Objective and Scope

The objective of this project was to conduct a LCA on the Green Group (GG) experiment test sections and compare the results to an asphalt mixture containing only virgin materials produced at common asphalt production mixture temperatures. This was completed by using Roadprint, designed by Pavia Systems. The LCA included material extraction, production, and construction. The use, rehabilitation, and end-of-life phases were not included in this assessment because the test sections only receive two years trafficking. No maintenance is expected during the short life of the pavements. Economic and social benefits of these mixtures were not quantified as they are outside the common LCA methodology and, thus, outside the scope of this report. Pavement performance and economics will be covered in other reports which are currently in development.

1.3 Organization of this Report

This report is divided into four chapters. Chapter 2 provides a description of the assessment procedure. Chapter 3 provides the results of the assessment process. Chapter 4 presents the final conclusions based on the results of this study.

CHAPTER 2 ASSESSMENT PROCEDURE

This chapter describes the data that was used to conduct the life-cycle assessment of the 2012 NCAT GG experiment. In addition to using the 2012 NCAT GG experiment, these test sections were compared to an experimental test section that was constructed in 2009 as part of the Group Experiment that contained all virgin materials. The 2009 test section was 7 inches in thickness compared to the 6 inches constructed in 2012; therefore, the thickness of the 2009 Group Experiment section was reduced for equivalent comparisons.

2.1 Roadprint

Roadprint is an online tool used to conduct a LCA on either new or rehabilitated pavements. The original work was completed by Lin (6) in 2012 while Pavia Systems put the program into web form. The tool requires knowledge of design and construction inputs in order to calculate the emissions and energy consumption for the construction process.

2.2 Material Inputs

The first phase of the LCA for each of the mixtures was to characterize the materials used for each test section. This required understanding the quantity of each material used.

Roadprint only allows two pavement layers to be used in its LCA procedure. One of those layers was considered the base material. The top layer of the pavement structure was a combination of the three mixtures (base, intermediate, and surface mixture) that made up the asphalt structure of the pavement. Therefore, weighted averages based on the total material mass of each pavement layer were used to determine the quantity of each material comprising the five test sections. All of the mix designs used for the actual NCAT Pavement Test Track mixtures are provided in Appendix A.

In addition to using weighted averages for material quantity, weighted averages were used to determine haul distances of the materials, specifically the aggregates. Roadprint places all aggregate into one of two categories: (1) virgin aggregate and (2) sand and gravel. Therefore, the limestone in the base/intermediate mixtures and the granite in the surface mixtures were both placed in the virgin aggregate category. A weighted average for the haul distance of the different aggregates used in the mixtures was calculated to assess the impact of trucking the aggregate to the plant.

Associated with the use of asphalt materials is the concept of feedstock energy. The International Organization for Standardization (ISO) 14044 defines this as "heat of combustion of a raw material input that is not used as an energy source to a product system, expressed in terms of higher heating value or lower heating value" (7, Section 4.2.3.3.2). In this study it was assumed to be 40.2 MJ/kg. In many cases, feedstock energy is negatively associated with the material due to its ability to produce greenhouse gases or be used as energy one day; however, in the case of asphalt, the feedstock energy is, in fact, being sequestered instead of released.

According to ISO, feedstock energy should be presented in a true LCA; however, it will be presented separately from the other energies associated with materials.

2.2.1 Base Materials

Each test section used six inches of granular aggregate base, which was located approximately 20 miles from the Test Track. Since all of the test sections contained the same quantity of material, the base material did not have an effect on the difference in overall energy consumption or emissions contributions between the different test sections.

2.2.2 Test Section N5

Test section N5 contained asphalt mixtures comprised of moderate and high levels of reclaimed asphalt pavement (RAP). The surface mixture was a warm mix asphalt (WMA) produced at 270°F. A foaming technology (Astec Double Barrel® Green) using 20% RAP was placed 1.4 inches thick. The intermediate mixture was produced using a foaming WMA at 285°F using 35% RAP at a thickness of 1.7 inches. The same mixture was produced at 280°F and placed 3 inches thick as the base layer. The unfractionated RAP used in all three mixtures had an asphalt binder content of 4.5%, which was used to replace virgin binder in the mix. In all cases it was assumed that 100 percent of the RAP binder could be used to replace virgin binder.

Table 3 provides an overview of the three mixture designs, production temperature, and in situ densities.

TABLE 3 Design, Production, and Placement Overview of N5

Parameter \ Mixture	Surface	Intermediate	Base
Classification	Superpave 9.5mm fine-graded	Superpave 19.0 mm fine-graded	Superpave 19.0 mm fine-graded
Superpave, N_{design}	80 gyrations	80 gyrations	80 gyrations
Type	Warm Mix Asphalt (foamed technology)	Warm Mix Asphalt (foamed technology)	Warm Mix Asphalt (foamed technology)
Reclaimed Asphalt Pavement (RAP)	Non-fractionated 20%, $P_{b\text{-}RAP}$ = 0.9%	Non-fractionated 35%, $P_{b\text{-}RAP}$ = 1.6%	Non-fractionated 35%, $P_{b\text{-}RAP}$ = 1.6%
Recycled Asphalt Shingles (RAS)	n/a	n/a	n/a
Ground Tire Rubber (GTR)	n/a	n/a	n/a
Fly Ash	n/a	n/a	n/a
Virgin Asphalt Binder	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 4.7%	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 3.0%	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 3.0%
Design Asphalt Binder Content	P_b-total = 5.6	P_b-total = 4.6	P_b-total = 4.6

Production P_b, based on QA results	P_b = 5.2	P_b = 4.6	P_b = 4.6
Production Temperature	285˚F	285˚F	285˚F
Lift thickness	1.4 inches	1.7 inches	3.0 inches
In situ Density, based on QA results	Ave = 91.6%	Ave = 93.1%	Ave = 93.5%

P_b – Percent Asphalt Binder by Total Weight of Mix

Table 4 provides the percentages of the materials used in the three mixtures and the overall weighted average of the combined pavement structure (N5). In addition to determining the quantity of material used, the haul distances of the materials are also included in this table.

TABLE 4 Materials Used for N5

Material	Percentage by Layer by Total Mixture Weight			Weighted Average for Structure (%)	Haul Distance (miles)	Weighted Haul for Structure (miles)
	Surface	*Binder*	*Base*			
Virgin Binder (PG 67-22)	4.1	3.1	2.9	3.2	100	100
Granite	67.1	--	--	--	28	--
Limestone	--	42.2	42.4	--	5	--
Virgin Agg	67.1	42.2	42.4	47.9	--	13
Sand	9.7	21.1	21.1	18.7	41	41
RAP	19.1	33.6	33.6	30.2	10	10

2.2.3 Test Section S5

Test section S5 contained asphalt mixtures with high levels of RAP. The surface mixture was stone matrix asphalt (SMA) placed warm (285°F) using a foaming technology. The SMA included 25% of a coarse fractionated RAP and an asphalt binder content of 4%. In addition to RAP, 4% fly ash was used as mineral filler in the mixture. This mix was 1 inch thick. The intermediate mixture was a standard Superpave mixture containing 30% coarse RAP and 20% fine RAP. The fine RAP had 5% asphalt binder content. This was used in the intermediate mixture which was produced using a foaming technology at 2.4 inches thick; however, in order to achieve target density, the mixture was produced at 330°F. The base mixture used a highly modified binder in combination with 35% unfractionated RAP and was placed 2.7 inches thick at 285°F.

Table 5 provides an overview of the three mixture designs, production temperature, and in situ densities.

Table 6 provides the percentages of the materials used in the three mixtures and the overall weighted average of the combined pavement structure (S5). In addition to determining the quantity of material used, the haul distances of the materials are also included in this table.

TABLE 5 Design, Production, and Placement Overview of S5

Parameter \ Mixture	Surface	Intermediate	Base
Classification	SMA	Superpave 19.0 mm Fine-graded	Superpave 19.0 mm fine-graded
Superpave, N_{design}	50 blows	80 gyrations	80 gyrations
Type	Warm Mix Asphalt (foamed technology)	Warm Mix Asphalt (foamed technology)	Warm Mix Asphalt (chemical additive)
Reclaimed Asphalt Pavement (RAP)	Coarse-fractionated 25%, $P_{b\text{-}RAP}$ = 1.0%	Coarse-fractionated 30%, $P_{b\text{-}RAP}$ = 1.2% Fine-fractionated 20%, $P_{b\text{-}RAP}$ = 1.0%	Non-fractionated 35%, $P_{b\text{-}RAP}$ = 1.6%
Recycled Asphalt Shingles (RAS)	n/a	n/a	n/a
Ground Tire Rubber (GTR)	n/a	n/a	n/a
Fly Ash	4.0%	n/a	n/a
Virgin Asphalt Binder	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 5.3%	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 2.6%	Source: PG Grade: 76-22E $P_{b\text{-}v}$ = 3.0%
Design Asphalt Binder Content	P_b-total = 6.3	P_b-total = 4.8	P_b-total = 4.6
Production P_b, based on QA results	P_b = 6.3	P_b = 5.0	P_b = 4.6
Production Temperature	285˚F	285˚F	285˚F
Lift thickness	1.0 inches	2.4 inches	2.7 inches
In situ Density, based on QA results	Ave = 93.5%	Ave = 95.8%	Ave = 92.8%

P_b – Percent Asphalt Binder by Total Weight of Mix

TABLE 6 Materials Used for S5

Material	Percentage by Layer by Total Mixture Weight			Weighted Average for Structure (%)	Haul Distance (miles)	Weighted Haul for Structure (miles)
	Surface	*Binder*	*Base*			
Virgin Binder (PG 67-22)	5.0	2.4	--	1.7	100	100
Virgin Binder (PG 76-22E)	--	--	3.0	1.3	100	100
Granite	67.2	--	--	--	28	--
Limestone	--	28.4	42.7	--	5	--
Virgin Agg	67.2	28.4	42.7	41.0	--	12.2
Sand	--	20.5	20.4	17.1	41	41
RAP	23.2	48.7	33.9	38.1	5	5
Fly Ash	3.8	--	--	0.6	130	130
Cellulose	0.8	--	--	0.2	--	--

2.2.4 Test Section S6

Test section S6 contained asphalt mixtures with both recycled asphalt shingles (RAS) and RAP. The surface mixture was a SMA placed warm (275°F) using a foaming technology. The SMA included 5% post-consumer RAS, which had an asphalt binder content of 20%. Four percent fly ash was also used in this SMA, and it was placed 1.3 inches thick. The intermediate mixture was a standard Superpave mixture containing 25% unfractionated RAP and 5% RAS. It was produced using Evotherm® Q1 at 280°F. The base mixture used a highly modified binder in combination with 25% unfractionated RAP and was placed 2.3 inch thick at 285°F using foaming technology.

Table 7 provides an overview of the three mixture designs, production temperature, and in situ densities.

TABLE 7 Design, Production, and Placement Overview of S6

Parameter \ Mixture	Surface	Intermediate	Base
Classification	SMA	Superpave 19.0 mm Fine-graded	Superpave 19.0 mm fine-graded
Superpave, N_{design}	50 blows	80 gyrations	80 gyrations
Type	Warm Mix Asphalt (foamed technology)	Warm Mix Asphalt (chemical additive)	Warm Mix Asphalt (foaming technology)
Reclaimed Asphalt Pavement (RAP)	n/a	Non-fractionated 25%, P_{b-RAP} = 1.1%	Non-fractionated 25%, P_{b-RAP} = 1.1%
Recycled Asphalt Shingles (RAS)	Post-Consumer RAS 5%, P_{b-RAS} = 1.0%	Post-Consumer RAS 5%, P_{b-RAS} = 1.0%	n/a
Ground Tire Rubber (GTR)	n/a	n/a	n/a
Fly Ash	4.0%	n/a	n/a
Virgin Asphalt Binder	Source: PG Grade: 67-22 P_{b-v} = 5.3%	Source: PG Grade: 67-22 P_{b-v} = 2.8%	Source: PG Grade: 76-22 P_{b-v} = 4.2%
Design Asphalt Binder Content	P_b-total = 6.7	P_b-total = 4.9	P_b-total = 5.4
Production P_b, based on QA results	P_b = 5.5	P_b = 4.9	P_b = 5.3
Production Temperature	275˚F	280˚F	285˚F
Lift thickness	1.3 inches	2.4 inches	2.3 inches
In situ Density, based on QA results	Ave = 92.1%	Ave = 94.0%	Ave = 96.5%

P_b – Percent Asphalt Binder by Total Weight of Mix

Table 8 provides the percentages of the materials used in the three mixtures and the overall weighted average of the combined pavement structure (S6). In addition to determining the quantity of material used, the haul distances of the materials are also included in this table.

TABLE 8 Materials Used for S6

Material	Percentage by Layer by Total Mixture Weight			Weighted Average for Structure (%)	Haul Distance (miles)	Weighted Haul for Structure (miles)
	Surface	*Binder*	*Base*			
Virgin Binder (PG 67-22)	4.3	2.7	3.1	3.2	100	100
Granite	87.1	--	--	--	28	--
Limestone	--	48.6	42.6	--	5	--
Virgin Agg	87.1	48.6	--	54.7	--	7.5
Sand	--	19.5	20.4	15.6	41	41
RAP	--	24.3	33.9	22.7	5	5
RAS	4.8	4.9	--	3.0	--	--
Fly Ash	3.8	--	--	0.8	130	130

2.2.5 Test Section S13

Test section S13 contained asphalt mixtures comprised which included ground tire rubber (GTR) modified asphalt binders and RAP. The surface mixture was stone matrix asphalt (SMA) placed warm (275°F) using a chemical additive technology. The SMA included a binder modified with 12% GTR. Fly ash was used as mineral filler in the mixture, which was placed 1.2 inches thick. The intermediate mixture was a standard Superpave mixture containing 35% unfractionated RAP and a GTR modified binder. It was produced using a foaming technology at 3.2 inches thick and 280°F. The base mixture was a GTR modified gap-graded asphalt mixture with 20% rubber by weight of binder. This mix was produced warm using Evotherm® Q1 at 300°F.

Table 9 provides an overview of the three mixture designs, production temperature, and in situ densities.

TABLE 9 Design, Production, and Placement Overview of S13

Parameter \ Mixture	Surface	Intermediate	Base
Classification	SMA	Superpave 19.0 mm Fine-graded	Arizona Gap-graded
Superpave, N_{design}	50 blows	80 gyrations	75 blows
Type	Warm Mix Asphalt (chemical additive)	Warm Mix Asphalt (foaming technology)	Warm Mix Asphalt (chemical technology)
Reclaimed Asphalt Pavement (RAP)	n/a	Non-fractionated 35%, $P_{b\text{-}RAP}$ = 1.6%	n/a
Recycled Asphalt Shingles (RAS)	n/a	n/a	n/a
Ground Tire Rubber (GTR)	12%	12%	20%
Fly Ash	5.0%	n/a	n/a
Virgin Asphalt Binder	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 5.4%	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 3.2%	Source: PG Grade: 67-22 $P_{b\text{-}v}$ = 7.8%
Design Asphalt Binder Content	P_b-total = 6.4%	P_b-total = 4.8%	P_b-total = 7.7%
Production P_b, based on QA results	P_b = 5.7%	P_b = 4.8%	P_b = 7.2%
Production Temperature	275˚F	280˚F	300˚F
Lift thickness	1.2 inches	3.2 inches	2.0 inches
In situ Density, based on QA results	Ave = 92.9%	Ave = 94.4%	Ave = 92.3%

P_b – Percent Asphalt Binder by Total Weight of Mix

Table 10 provides the percentages of the materials used in the three mixtures and the overall weighted average of the combined pavement structure (S13). In addition to determining the quantity of material used, the haul distances of the materials are also included in this table.

TABLE 10 Materials Used for S13

Material	Percentage by Layer by Total Mixture Weight			Weighted Average for Structure (%)	Haul Distance, (miles)	Weighted Haul for Structure (miles)
	Surface	*Binder*	*Base*			
Virgin Binder (GTR Binder)	5.1	3.1	6.7	4.6	100	100
Granite	89.2	--	--	--	28	--
Limestone	--	42.6	85.8	--	5	--
Virgin Agg	89.2	42.6	85.8	64.8	--	11.2
Sand	--	20.3	6.5	12.2	41	41
RAP	--	34.0	--	17.0	5	5
Fly Ash	5.7	--	--	1.1	130	130
Hydrated Lime	--	--	1.0	0.3	5	5

2.2.6 Virgin Hot Mix Asphalt

While there was not a control virgin hot mix asphalt (HMA) placed on the Test Track in 2012, it was important to estimate the reduction in emission and energy consumption due to the use of WMA and recycled materials. The authors understand using a completely virgin mix is not common practice in the United States today as the national average of recycled material usage continues to rise; however, conventional mixture designs using the Test Track materials were not available to the author for comparison. Therefore, an experimental test section (S9) from the 2009 Test Track was used as the mixture for this experimental virgin section. Section S9 was part of the 2009 Test Track Group Experiment to be the control section for HMA and high RAP test sections. One difference between the 2009 and 2012 designs was the thickness of the test section; therefore, the thicknesses of sections S6 were used for the new S9 design.

Table 11 provides an overview of the three mixture designs, production temperature, and in situ densities.

TABLE 11 Design, Production, and Placement Overview of Control Mix

Parameter \ Mixture	Surface	Intermediate	Base
Classification	Superpave 9.5 mm Fine-graded	Superpave 19.0 mm Fine-graded	Arizona Gap-graded
Superpave, N_{design}	80 gyrations	80 gyrations	75 blows
Type	Hot Mix Asphalt	Hot Mix Asphalt	Hot Mix Asphalt
Reclaimed Asphalt Pavement (RAP)	n/a	n/a	n/a
Recycled Asphalt Shingles (RAS)	n/a	n/a	n/a
Ground Tire Rubber (GTR)	n/a	n/a	n/a
Fly Ash	n/a	n/a	n/a
Virgin Asphalt Binder	Source: PG Grade: 76-22 P_{b-v} = 6.1%	Source: PG Grade: 76-22 P_{b-v} = 4.4%	Source: PG Grade: 67-22 P_{b-v} = 4.7%
Design Asphalt Binder Content	P_b-total = 5.8%	P_b-total = 4.7%	P_b-total = 4.6%
Production Pb, based on QA results	P_b = 6.1%	P_b = 4.4%	P_b = 4.7%
Production Temperature	335˚F	335˚F	325˚F
Lift thickness	1.2 inches	2.3 inches	2.4 inches
In situ Density, based on QA results	Ave = 93.1%	Ave = 92.8%	Ave = 92.6%

P_b – Percent Asphalt Binder by Total Weight of Mix

Table 12 shows the percentages of the materials used in the three mixtures and the overall weighted average of the combined theoretical pavement structure. In addition to determining the quantity of material used, the haul distances of the materials are also included in this table.

TABLE 12 Materials Used for Control HMA

Material	Percentage by Layer by Total Mixture Weight			Weighted Average for Structure (%)	Haul Distance (miles)	Weighted Haul for Structure (miles)
	Surface	*Binder*	*Base*			
Virgin Binder	5.9	4.7	4.5	4.8	100	100
Granite	90.0	--	--	--	28	--
Limestone	--	75.3	71.0	--	5	--
Virgin Agg	90.0	75.3	71.0	75.8	--	15.5
Sand	--	20.0	24.5	18.7	41	41
Fly Ash	3.8	--	--	0.6	130	130
Cellulose	0.3	--	--	0.1	--	--

2.3 Mixture Production and Construction

In order to account for the amount of energy and emissions from the production and construction process, Roadprint requires one input construction data for each of the pavement sections. Each test section was produced using the same equipment with similar rolling patterns and compactive efforts. The main difference in the production process occurred through the use of WMA technologies, which allowed the plant to run at a lower temperature and, thus, use less fuel. Table 13 provides the equipment included in the production and construction phase. When data were not available, standard inputs provided by the software were used.

TABLE 13 Construction Equipment

Equipment	Working Time	Efficiency Factor (%)	Rate (ft/min)
Paver	100%	85	35
Breakdown Roller	100%	85	300
Finisher Roller	75%	85	300
MTV	100%		
	Production Rate	**Distance to site**	**Haul Speed**
Plant	300 ton/hr	5.1 miles	30 mph

Using these data as well as the materials data, Roadprint was used to calculate energy consumption and emissions for each of the five test sections.

CHAPTER 3 LCA RESULTS

This chapter describes the results of the LCA that was conducted on the six previously described pavement test sections. It was assumed that instead of constructing test sections which were 200 feet in length, that one mile of the pavement structure was constructed using a lane that was 12 feet wide. In this section four comparisons will be made. The energy used for materials, transportation and production will be compared between the test sections as well as the CO_2 emissions from material extraction, mixture production and construction, and material transport.

3.1 Energy Consumption and CO_2 due to Raw Material Extraction and Production

Figure 3 shows the amount of energy required to extract and process the raw materials described in Chapter 2. As can be seen, all four mixtures in the GG experiment used less energy during the production phase than the control. Table 14 shows the percent savings in energy for each of the test sections. The reduction in energy from material can be tied to the use of recycled materials. As the recycled content went up, with the exception of the RAS test section, the amount of energy consumed lessened. The test section with RAS (S6) had a lower recycled content but a higher percent energy saved than section N5; however, this can be explained because of the additional binder that is in RAS compared to RAP. Additional virgin binder did not have to be produced for this test section because the RAS contributed 20% binder to the mix.

The amount of CO_2 produced for each test section is shown in Figure 4. Each of the test sections in the GG experiment reduced the CO_2 produced during the material extraction and production phase. Table 8 also shows the percent savings for each of the test sections. The section with the smallest reduction in CO_2 was the GTR test section; however, it also had the lowest quantity of materials (RAP and RAS) that replaced virgin aggregate and asphalt. When RAP and/or RAS were used in mixtures, over 25% CO_2 was saved from the materials phase alone.

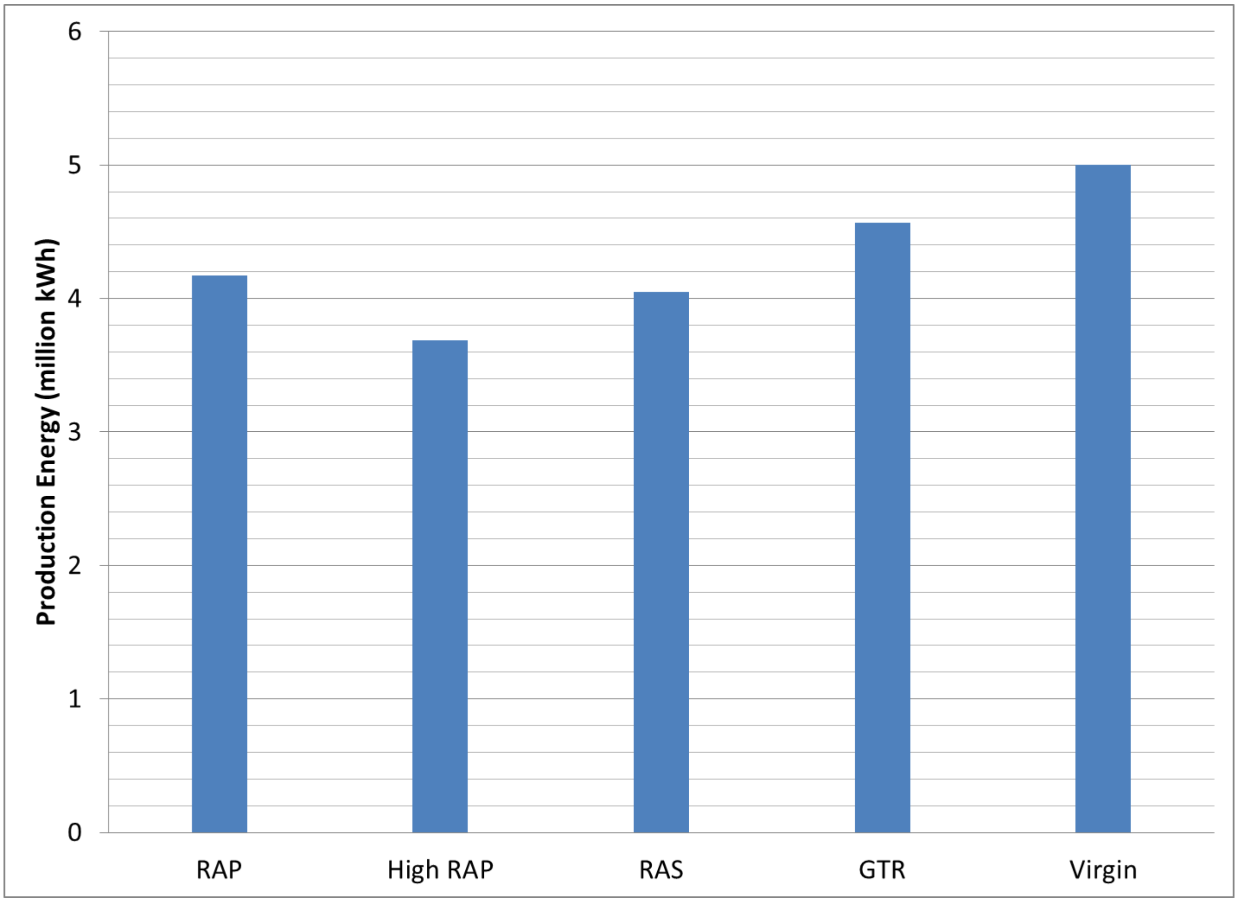

FIGURE 3 Production Energy for Extracting Processing Raw Materials

TABLE 14 Energy Saved During Material Extraction and Production Compared to Control Virgin HMA

Test Section	Recycled Content (%)	Energy Saved (%)	CO_2 Reduction (%)
N5/RAP	30.2	17	26
S5/High RAP	38.1	26	29
S6/RAS	25.7 (22.7% RAP + 3% RAS)	19	28
S13/GTR	16.6	9	5
Control/Virgin	0.0	Baseline	Baseline

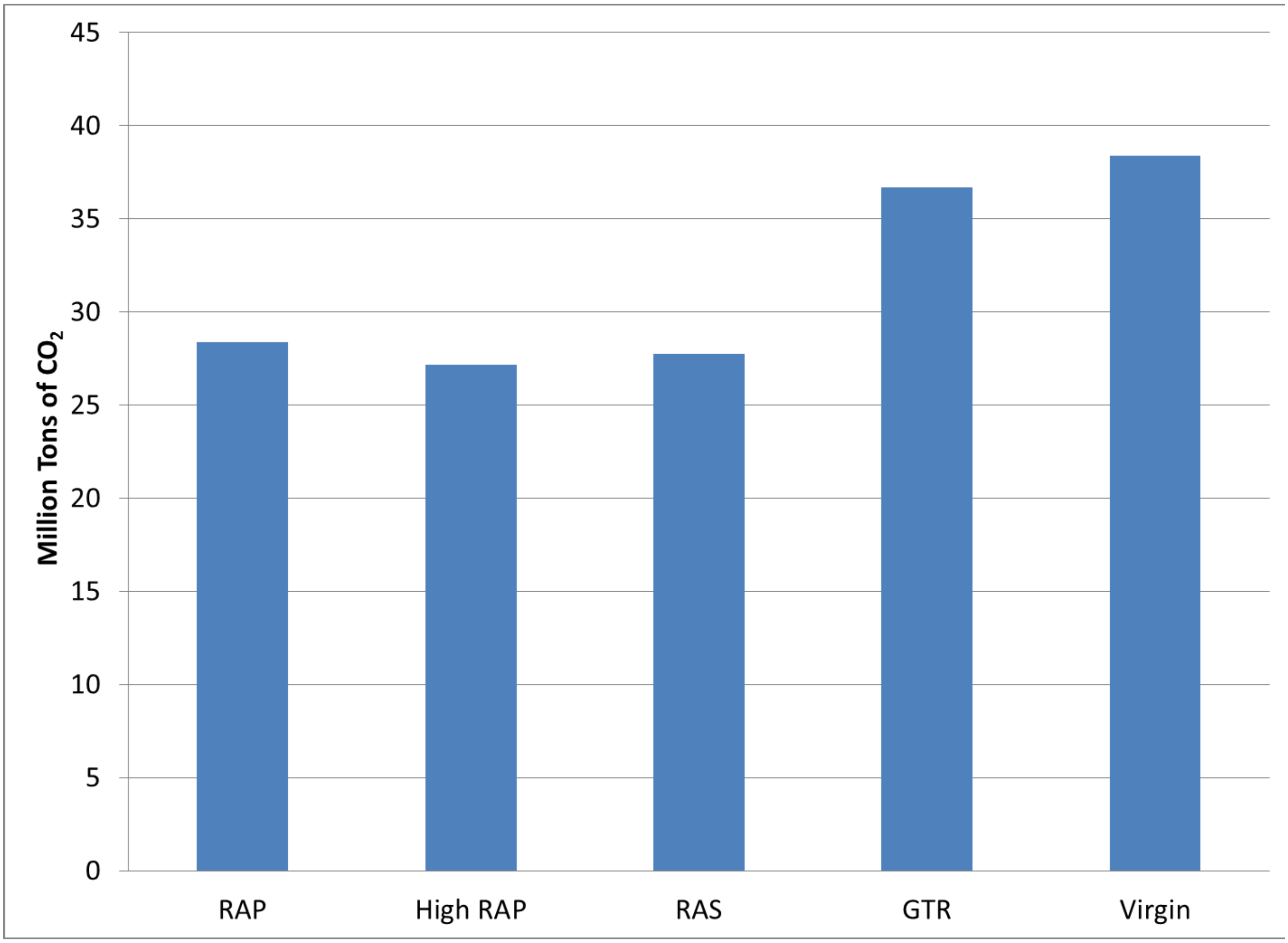

FIGURE 4 CO_2 from Material Extraction and Production

3.2 Energy Consumption and CO_2 due to Transportation of Raw Materials and Mixture

Figure 5 shows the amount of energy required to extract and process the raw materials described in Chapter 2. All four mixtures in the GG experiment used less energy during the transportation phase than the virgin HMA mixture. Table 9 shows the percent savings in energy for each of the test sections. As can be seen, the reduction in energy from material can be tied to the use of recycled materials. Mixtures with recycled materials did not have to transport as much virgin aggregate and asphalt allowing energy consumption for the transport of raw materials to be reduced.

The amount of CO_2 produced for transporting virgin material and mix for each test section is shown in Figure 6. Each of the test sections in the GG experiment reduced the CO_2 produced during the transportation phase. Table 15 also shows the percent savings for each of the test sections. Recycled content alone does not explain the result of the CO_2 reduction; however, the reduction can be explained when one couples the effect of recycled materials and lower virgin aggregate haul distances. This shows the importance of using local materials when possible to reduce the pavement's overall impact on the environment. In addition to providing environmental benefits, using locally available aggregate increases a mixture's sustainability by being more economical.

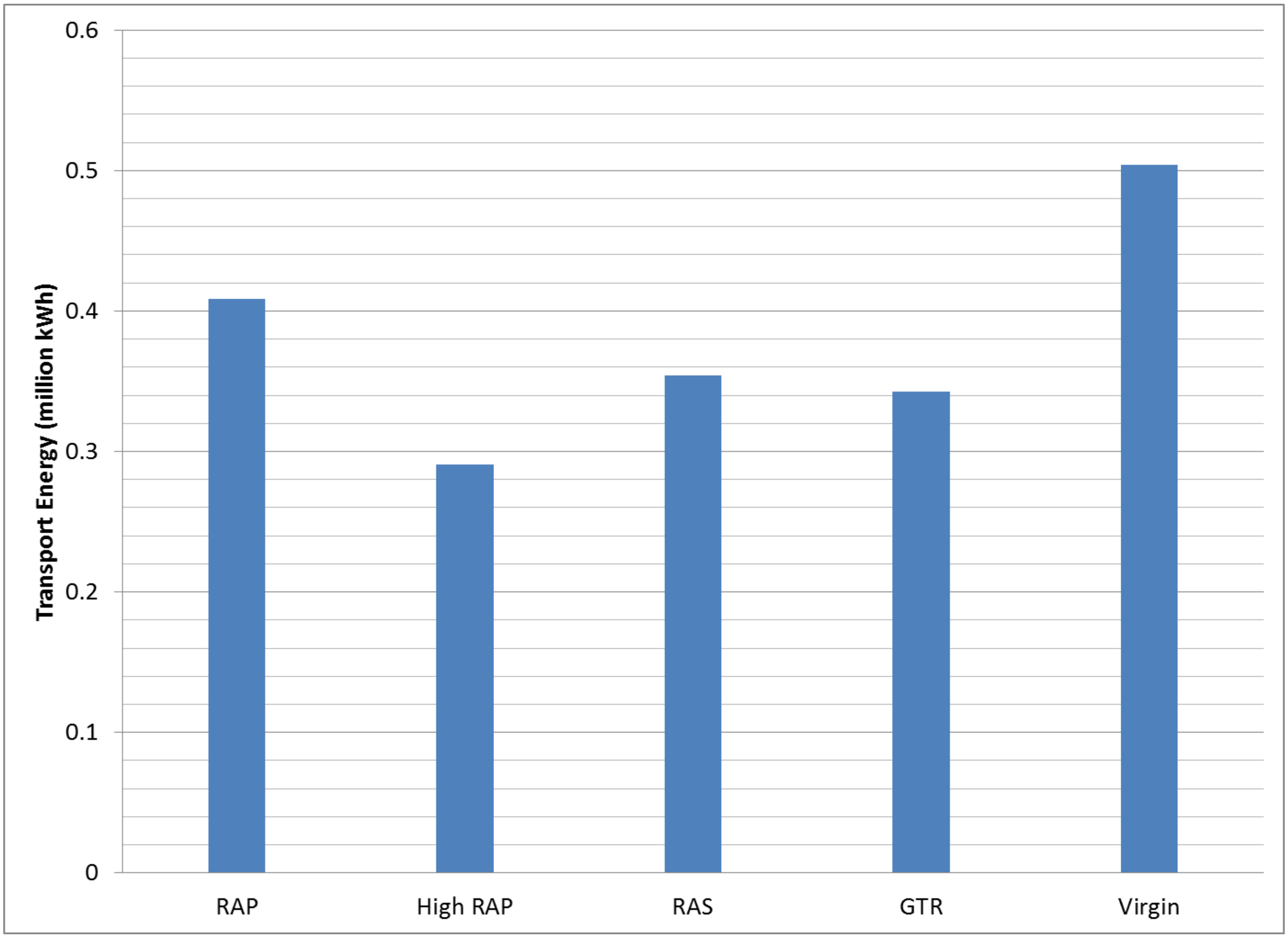

FIGURE 5 Transportation Energy

TABLE 15 Energy Saved During Material Raw Material and Mixture Transportation Compared to Control HMA

Test Section	Recycled Content (%)	Haul Distance (miles)	Energy Saved (%)	CO_2 Reduction(%)
N5/RAP	30.2	13	19	26
S5/High RAP	38.1	12.2	42	6
S6/RAS	25.7 (22.7% RAP + 3% RAS)	7.5	30	39
S13/GTR	16.6	11.2	32	9
Control/Virgin	0.0	15.1	Baseline	Baseline

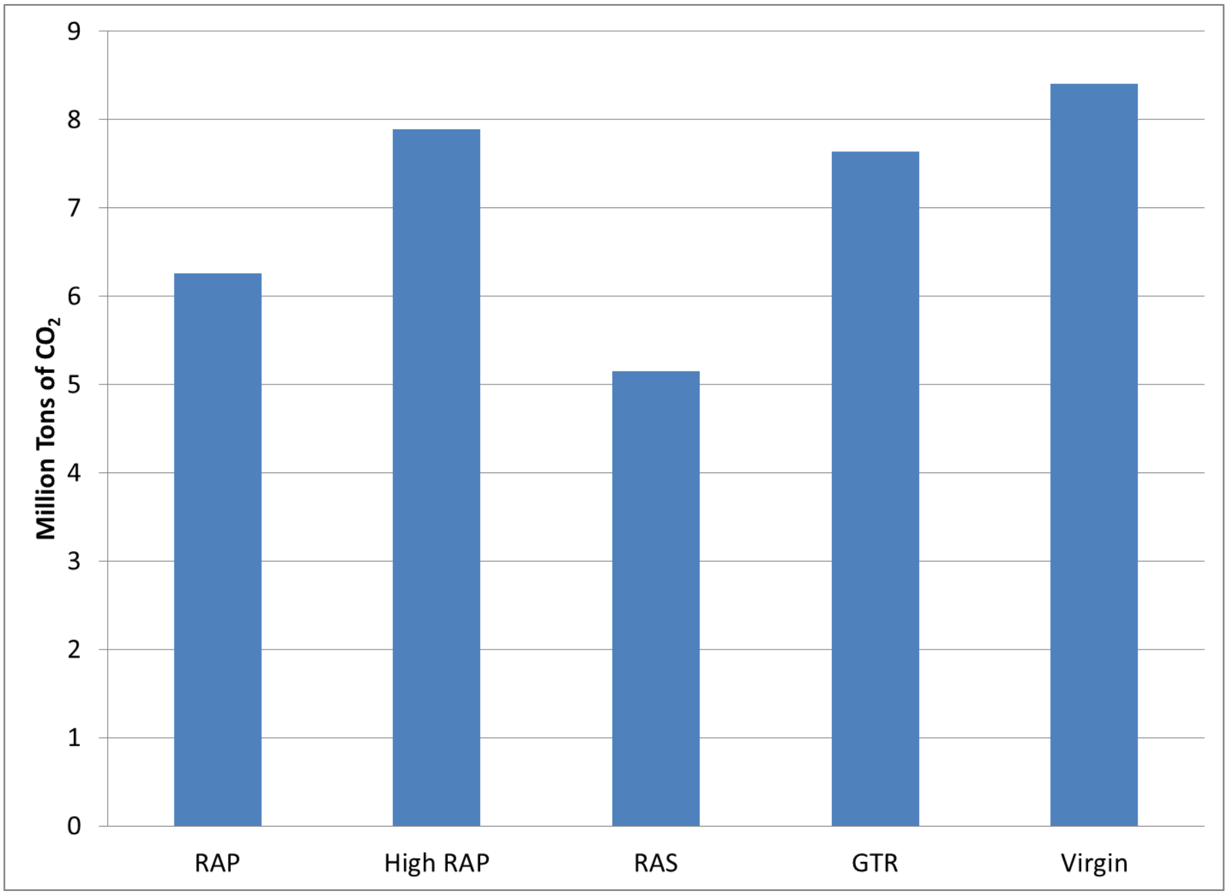

FIGURE 6 CO_2 from Raw Material and Mixture Transportation

3.3 Energy Consumption and CO_2 due to Asphalt Mixture Production

Figure 7 shows the amount of energy required to produce the test sections described in Chapter 2. As can be seen, all four mixtures in the GG experiment used less energy during the production phase than the control virgin HMA mixture. Table 16 shows the percent savings in energy for each of the test sections. Recycled content does not affect energy consumption during mixture production. The effect on mixture production is tied to using WMA technologies and reducing the temperature at the plant.

The amount of CO_2 produced for each test section is shown in Figure 8. Each of the test sections in the GG experiment reduced the amount of CO_2 produced during the mixture production phase. Most of the test sections saved 5 to 9 percent CO_2 at the plant due to temperature reduction and fuel savings.

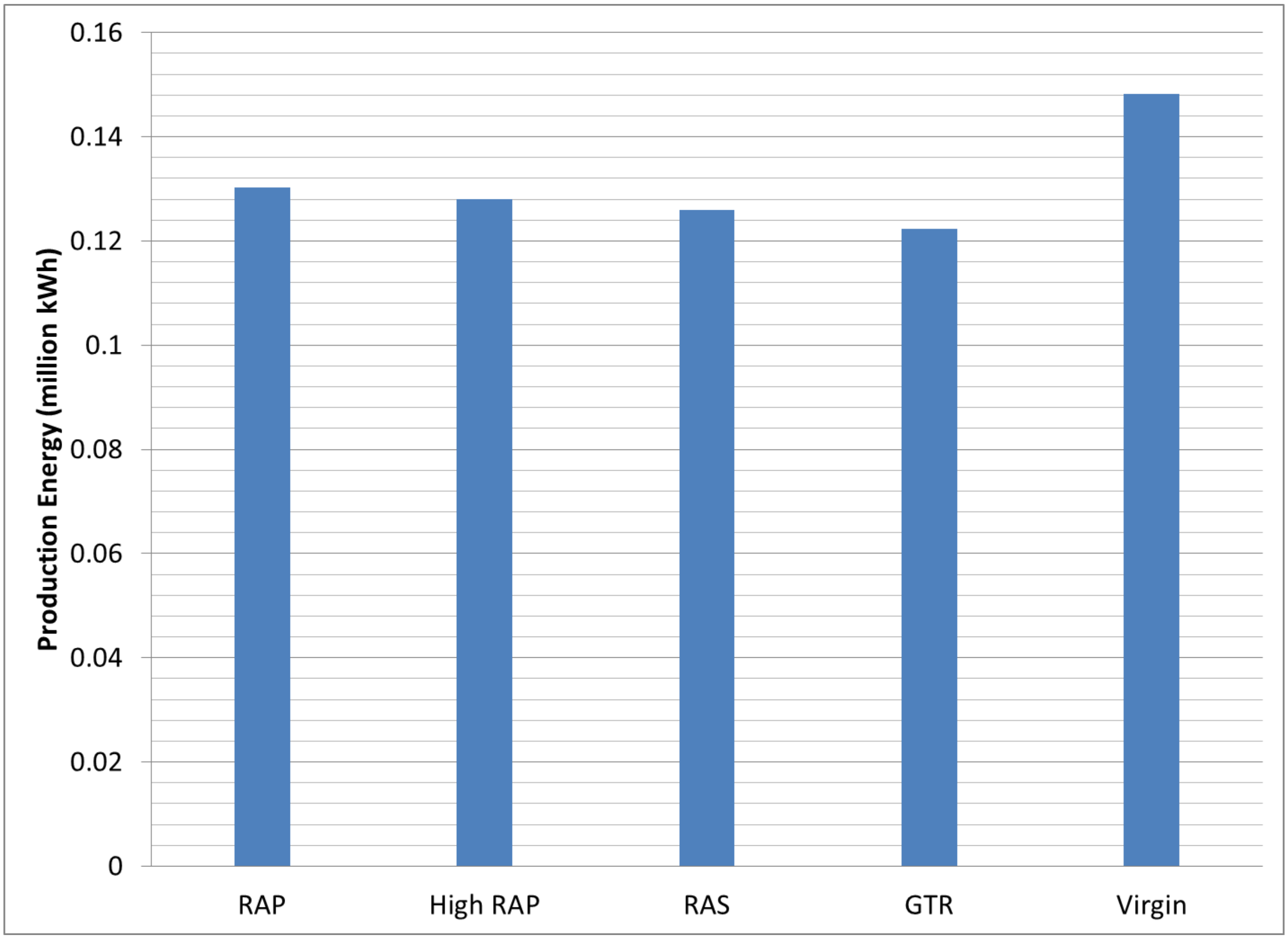

FIGURE 7 Asphalt Mixture Production Energy

TABLE 16 Energy Saved and CO_2 Reduced During Asphalt Mixture Production Compared to Control HMA

Test Section	Energy Saved (%)	CO_2 Reduction (%)
N5/RAP	12	6
S5/High RAP	13	7
S6/RAS	15	9
S13/GTR	17	9
Control/Virgin	Baseline	Baseline

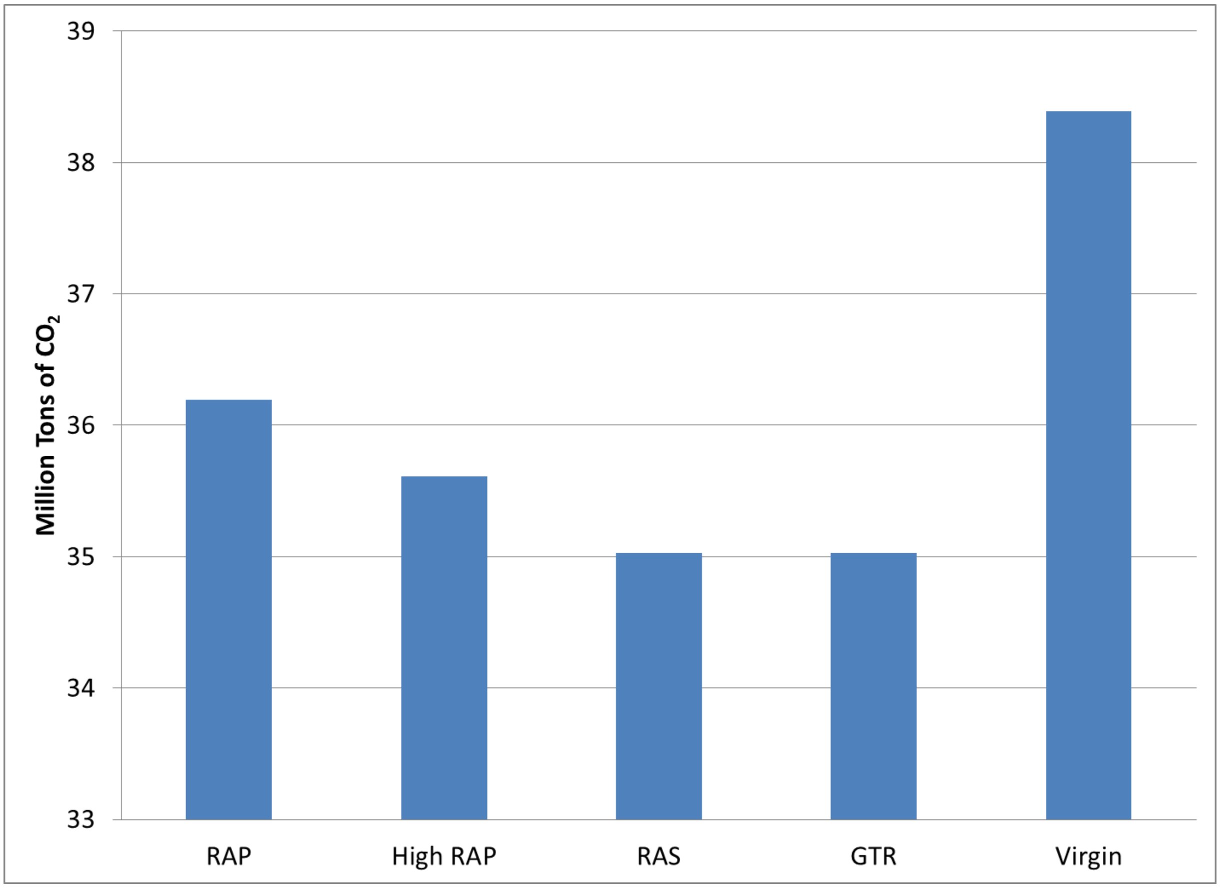

FIGURE 8 CO_2 from Asphalt Mixture Production

3.4 Feedstock Energy for Asphalt

As noted earlier, ISO standards state feedstock should be included in LCAs; however, in the case of asphalt pavements, the energy is sequestered in the pavements with no intention of ever being used as an energy source. Therefore, to comply with ISO standards, the feedstock energy for the five sections is presented in Table 17.

TABLE 17 Feedstock Energy

Section	Feedstock Energy (thousand kWh)
N5/RAP	517.7
S5/High RAP	484.4
S6/RAS	500.0
S13/GTR	727.2
Virgin	881.9

CHAPTER 4 CONCLUSIONS

This chapter describes the conclusions and recommendations based on the previously detailed research methodology and results.

4.1 Conclusions

Sustainability has become a recent focus in the pavement community. Sustainable development is defined under the "triple-bottom line," where social, environmental, and economic impacts are assessed. For this study, only the environmental element of sustainable development was explored. The Roadprint© Life-cycle Assessment (LCA) tool by Pavia Systems was used to compare the relative benefit of the NCAT GG Experiment to an idealized virgin section. This comparison focused on the areas where the sections differ and does not include all of the elements associated with a full LCA, which include: uses phase, maintenance and rehabilitation, and end-of-life.

- Using recycled materials to replace virgin aggregates in asphalt mixtures will reduce both the energy consumed and CO_2 produced during raw material extraction and processing. In this study, using recycled materials saved between 9 and 26 percent energy and reduced CO_2 production by 5 to 29 percent.
- Using the combination of recycled materials and local materials reduces energy required to transport raw materials and the asphalt mixture. A reduction in CO_2 is also attributed to this practice. For the Test Track mixtures, between 19 and 42 percent energy was saved and CO_2 was reduced by 6 to 39 percent.
- Using lower temperatures by incorporating WMA technologies into asphalt mixtures will reduce energy needs and CO_2 produced at the plant. This energy reduction, in reality, will be based on the temperature reduction associated with its use. 12 to 17 percent less energy was needed to produce the WMA mixtures in this study. 6 to 9 percent less CO_2 was produced in this case study.

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7. International Organizations for Standardization. ISO 14044:2006b – Environmental Management – Life Cycle Assessment – Requirements and Guidelines. Geneva, 2006.

APPENDIX A MIXTURE DESIGN AND CONSTRUCTION DATA

Quadrant: N
Section: 5
Sublot: 1

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	Granite/RAP/Sand
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	100	100
12.5 mm (1/2"):	100	100
9.5 mm (3/8"):	99	99
4.75 mm (#4):	74	73
2.36 mm (#8):	52	51
1.18 mm (#16):	38	40
0.60 mm (#30):	26	29
0.30 mm (#50):	16	18
0.15 mm (#100):	10	11
0.075 mm (#200):	6.2	7.0
Binder Content (Pb):	5.6	5.2
Eff. Binder Content (Pbe):	5.1	4.7
Dust-to-Binder Ratio:	1.2	1.5
Rice Gravity (Gmm):	2.459	2.494
Avg. Bulk Gravity (Gmb):	2.361	2.414
Avg Air Voids (Va):	4.0	3.2
Agg. Bulk Gravity (Gsb):	2.647	2.669
Avg VMA:	15.8	14.2
Avg. VFA:	75	77

Construction Diary

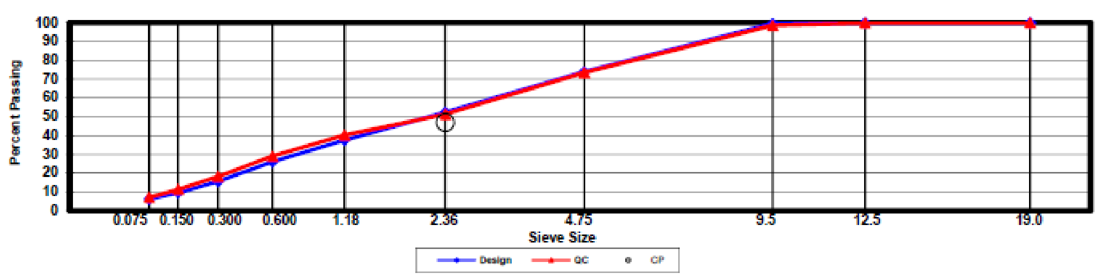
Relevant Conditions for Construction

Completion Date:	August 20, 2012
24 Hour High Temperature (F):	84
24 Hour Low Temperature (F):	71
24 Hour Rainfall (in):	0.01
Planned Subot Lift Thickness (in):	1.3
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	5.2
89 Columbus Granite	41.0
M10 Columbus Granite	29.0
Shorter Coarse Sand	10.0
EAP Unfractionated RAP	20.0
Green Foam	2.0

As-Built Sublot Lift Thickness (in):	1.4
Total Thickness of All 2012 Sublots (in):	6.1
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.05
Approx. Avg. Temperature at Plant (F):	270
Avg. Measured Mat Compaction:	91.6%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: N
Section: 5
Sublot: 2

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	Lms/RAP/Sand
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	99
19 mm (3/4"):	97	96
12.5 mm (1/2"):	88	90
9.5 mm (3/8"):	78	83
4.75 mm (#4):	56	61
2.36 mm (#8):	42	48
1.18 mm (#16):	32	39
0.60 mm (#30):	21	27
0.30 mm (#50):	12	15
0.15 mm (#100):	7	9
0.075 mm (#200):	5.0	5.5
Binder Content (Pb):	4.8	4.6
Eff. Binder Content (Pbe):	4.2	4.0
Dust-to-Binder Ratio:	1.2	1.4
Rice Gravity (Gmm):	2.546	2.540
Avg. Bulk Gravity (Gmb):	2.444	2.448
Avg Air Voids (Va):	4.0	3.6
Agg. Bulk Gravity (Gsb):	2.705	2.687
Avg VMA:	13.8	13.0
Avg. VFA:	72	72

Construction Diary

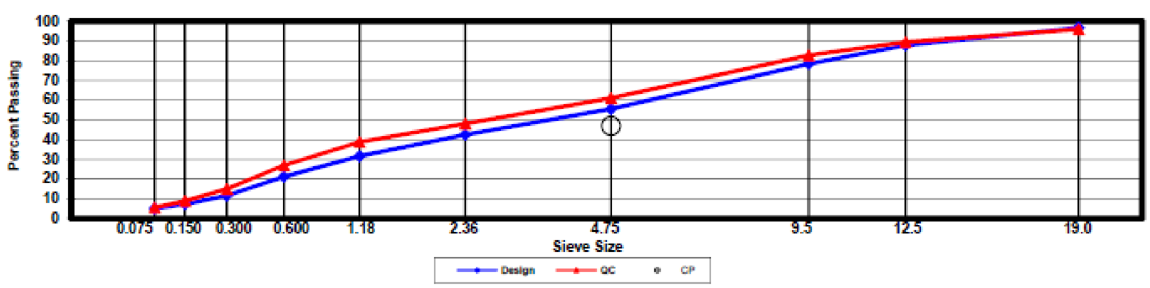
Relevant Conditions for Construction

Completion Date:	August 16, 2012
24 Hour High Temperature (F):	92
24 Hour Low Temperature (F):	72
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	2.3
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	4.6
78 Opelika Limestone	27.0
57 Opelika Limestone	17.0
Shorter Coarse Sand	21.0
EAP Unfractionated RAP	35.0
Green Foam	2.0

As-Built Sublot Lift Thickness (in):	1.7
Total Thickness of All 2012 Sublots (in):	6.1
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.05
Approx. Avg. Temperature at Plant (F):	285
Avg. Measured Mat Compaction:	93.1%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: N
Section: 5
Sublot: 3

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	Lms/RAP/Sand
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	99
19 mm (3/4"):	97	96
12.5 mm (1/2"):	88	91
9.5 mm (3/8"):	78	84
4.75 mm (#4):	56	63
2.36 mm (#8):	42	49
1.18 mm (#16):	32	39
0.60 mm (#30):	21	26
0.30 mm (#50):	12	14
0.15 mm (#100):	7	9
0.075 mm (#200):	5.0	5.7
Binder Content (Pb):	4.8	4.7
Eff. Binder Content (Pbe):	4.2	4.1
Dust-to-Binder Ratio:	1.2	1.4
Rice Gravity (Gmm):	2.546	2.563
Avg. Bulk Gravity (Gmb):	2.444	2.447
Avg Air Voids (Va):	4.0	4.5
Agg. Bulk Gravity (Gsb):	2.705	2.722
Avg VMA:	13.8	14.4
Avg. VFA:	72	69

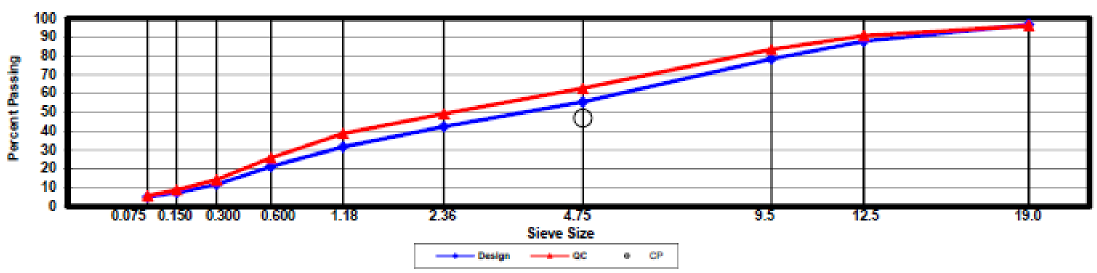
Construction Diary

Relevant Conditions for Construction

Completion Date:	August 15, 2012
24 Hour High Temperature (F):	92
24 Hour Low Temperature (F):	69
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	2.5
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	4.6
78 Opelika Limestone	27.0
57 Opelika Limestone	17.0
Shorter Coarse Sand	21.0
EAP Unfractionated RAP	35.0
Green Foam	2.0
As-Built Sublot Lift Thickness (in):	3.0
Total Thickness of All 2012 Sublots (in):	6.1
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NA
Undilluted Target Tack Rate (gal/sy):	NA
Approx. Avg. Temperature at Plant (F):	280
Avg. Measured Mat Compaction:	93.5%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

5/23/2013

Quadrant: S
Section: 5
Sublot: 1

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	SMA
Compactive Effort:	50 blows
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	Grn/C-FRAP/Flyash
Design Gradation Type:	SMA

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	100	100
12.5 mm (1/2"):	100	100
9.5 mm (3/8"):	98	98
4.75 mm (#4):	46	52
2.36 mm (#8):	21	25
1.18 mm (#16):	15	19
0.60 mm (#30):	13	15
0.30 mm (#50):	11	12
0.15 mm (#100):	9	10
0.075 mm (#200):	8.3	7.4
Binder Content (Pb):	6.9	6.3
Eff. Binder Content (Pbe):	6.3	5.8
Dust-to-Binder Ratio:	1.3	1.3
Rice Gravity (Gmm):	2.416	2.439
Avg. Bulk Gravity (Gmb):	2.319	2.330
Avg Air Voids (Va):	4.0	4.5
Agg. Bulk Gravity (Gsb):	2.644	2.649
Avg VMA:	18.4	17.6
Avg. VFA:	78	75

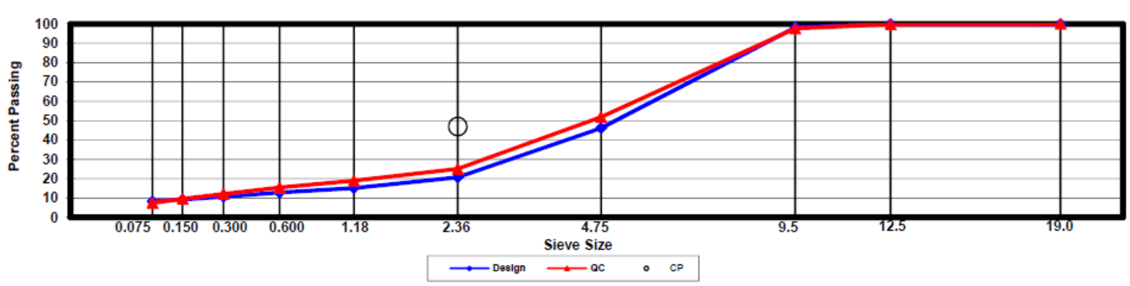
Construction Diary

Relevant Conditions for Construction

Completion Date:	May 22, 2013
24 Hour High Temperature (F):	87
24 Hour Low Temperature (F):	68
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	1.3
Paving Machine:	Blaw Knox

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	6.3
89 Columbus Granite	65.0
M10 Columbus Granite	6.0
EAP Coarse Fractionated RAP	25.0
Green Foam	2.0
Flyash	4.0
Cellulose	0.3
As-Built Sublot Lift Thickness (in):	1.0
Total Thickness of All 2012 Sublots (in):	6.0
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.08
Approx. Avg. Temperature at Plant (F):	285
Avg. Measured Mat Compaction:	93.5%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, S=South, L=Lee Rd 159), section number, and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

5/23/2013

Quadrant: S
Section: 5
Sublot: 2

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	RAP/Lms/Sand
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	96	96
12.5 mm (1/2"):	84	90
9.5 mm (3/8"):	77	81
4.75 mm (#4):	51	56
2.36 mm (#8):	41	45
1.18 mm (#16):	31	38
0.60 mm (#30):	20	27
0.30 mm (#50):	10	15
0.15 mm (#100):	6	9
0.075 mm (#200):	4.3	4.9
Binder Content (Pb):	4.8	5.0
Eff. Binder Content (Pbe):	4.1	4.3
Dust-to-Binder Ratio:	1.1	1.1
Rice Gravity (Gmm):	2.527	2.514
Avg. Bulk Gravity (Gmb):	2.426	2.439
Avg Air Voids (Va):	4.0	3.0
Agg. Bulk Gravity (Gsb):	2.676	2.670
Avg VMA:	13.7	13.2
Avg. VFA:	71	77

Construction Diary

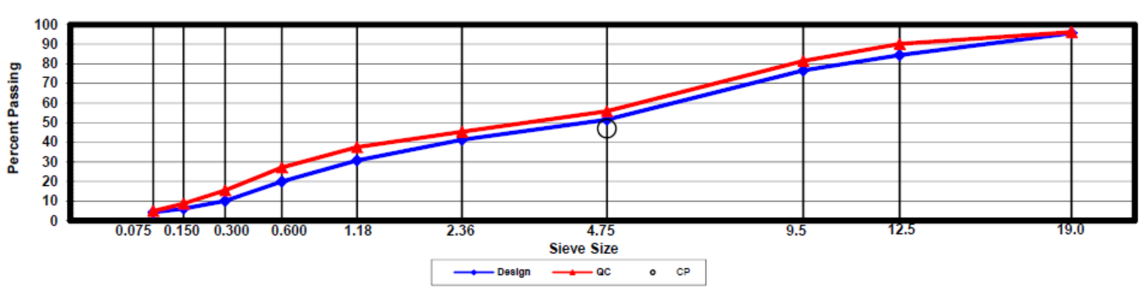
Relevant Conditions for Construction

Completion Date:	May 21, 2013
24 Hour High Temperature (F):	89
24 Hour Low Temperature (F):	65
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	2.3
Paving Machine:	Blaw Knox

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	5.0
78 Opelika Limestone	14.0
57 Opelika Limestone	15.0
Shorter Coarse Sand	21.0
EAP Coarse Fractionated RAP	30.0
EAP Fine Fractionated RAP	20.0
Green Foam	2.0

As-Built Sublot Lift Thickness (in):	2.4
Total Thickness of All 2012 Sublots (in):	6.0
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.10
Approx. Avg. Temperature at Plant (F):	330
Avg. Measured Mat Compaction:	95.8%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, S=South, L=Lee Rd 159), section number, and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

5/23/2013

Quadrant: S
Section: 5
Sublot: 3

Laboratory Diary

General Description of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	76-22E
Modifier Type:	NA
Aggregate Type:	Lms/Sand/RAP
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	97	98
12.5 mm (1/2"):	88	91
9.5 mm (3/8"):	78	84
4.75 mm (#4):	56	63
2.36 mm (#8):	42	48
1.18 mm (#16):	32	39
0.60 mm (#30):	21	27
0.30 mm (#50):	12	15
0.15 mm (#100):	7	8
0.075 mm (#200):	5.0	5.3
Binder Content (Pb):	4.7	4.7
Eff. Binder Content (Pbe):	4.1	4.1
Dust-to-Binder Ratio:	1.2	1.3
Rice Gravity (Gmm):	2.549	2.529
Avg. Bulk Gravity (Gmb):	2.447	2.436
Avg Air Voids (Va):	4.0	3.7
Agg. Bulk Gravity (Gsb):	2.705	2.682
Avg VMA:	13.7	13.5
Avg. VFA:	71	73

Construction Diary

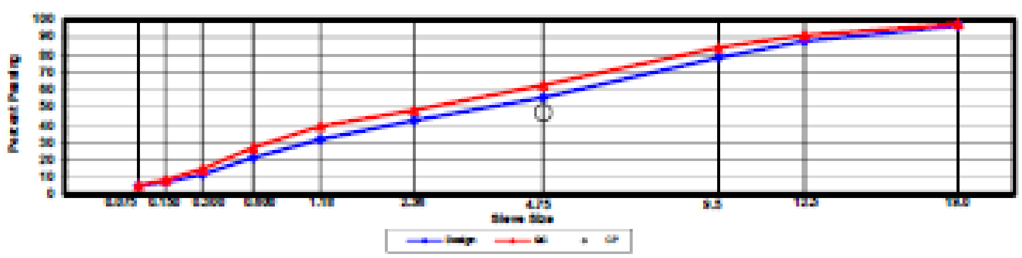
Relevant Conditions for Construction

Completion Date:	May 21, 2013
24 Hour High Temperature (F):	89
24 Hour Low Temperature (F):	65
24 Hour Rainfall (in):	0.00
Planned Sublot Lift Thickness (in):	2.5
Paving Machine:	Blaw Knox

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	4.7
78 Opelika Limestone	27.0
57 Opelika Limestone	17.0
Shorter Coarse Sand	21.0
EAP Unfractionated RAP	35.0
Evotherm Q1	0.5

As-Built Sublot Lift Thickness (in):	2.7
Total Thickness of All 2012 Sublots (in):	6.0
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NA
Undiluted Target Tack Rate (gal/sy):	NA
Approx. Avg. Temperature at Plant (F):	285
Avg. Measured Mat Compaction:	92.8%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, S=South, L=Lee Rd 159), section number, and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: S
Section: 6
Sublot: 1

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	SMA
Compactive Effort:	80 gyrations
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	Grn/Flyash/PC-RAS
Design Gradation Type:	SMA

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	100	100
12.5 mm (1/2"):	100	100
9.5 mm (3/8"):	100	100
4.75 mm (#4):	54	54
2.36 mm (#8):	25	24
1.18 mm (#16):	18	20
0.60 mm (#30):	15	16
0.30 mm (#50):	12	13
0.15 mm (#100):	11	11
0.075 mm (#200):	9.1	8.7
Binder Content (Pb):	6.7	5.5
Eff. Binder Content (Pbe):	6.3	5.1
Dust-to-Binder Ratio:	1.4	1.7
Rice Gravity (Gmm):	2.417	2.473
Avg. Bulk Gravity (Gmb):	2.320	2.383
Avg Air Voids (Va):	4.0	3.6
Agg. Bulk Gravity (Gsb):	2.651	2.667
Avg VMA:	18.5	15.6
Avg. VFA:	78	77

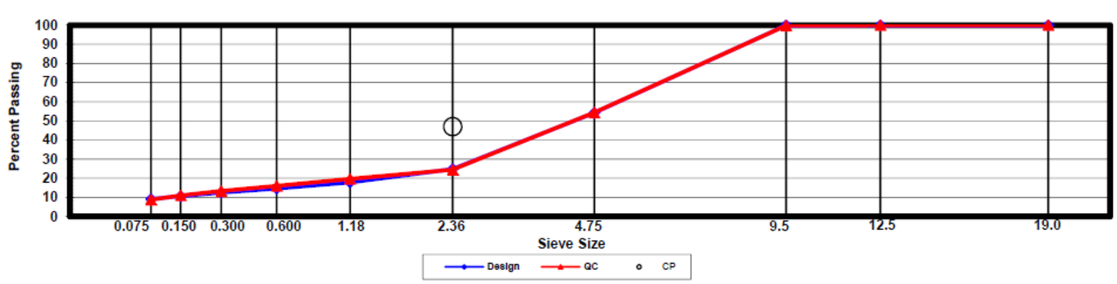
Construction Diary

Relevant Conditions for Construction

Completion Date:	August 23, 2012
24 Hour High Temperature (F):	91
24 Hour Low Temperature (F):	65
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	1.3
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	5.7
89 Columbus Granite	82.0
M10 Columbus Granite	9.0
Wedowee PC-RAS	5.0
Green Foam	2.0
Flyash	4.0
As-Built Sublot Lift Thickness (in):	1.3
Total Thickness of All 2012 Sublots (in):	6.0
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.05
Approx. Avg. Temperature at Plant (F):	275
Avg. Measured Mat Compaction:	92.1%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: S
Section: 6
Sublot: 2

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	67-22
Modifier Type:	NA
Aggregate Type:	Lms/RAP/Sand/RAS
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	99	99
19 mm (3/4"):	95	94
12.5 mm (1/2"):	80	85
9.5 mm (3/8"):	70	76
4.75 mm (#4):	51	57
2.36 mm (#8):	41	45
1.18 mm (#16):	30	36
0.60 mm (#30):	20	25
0.30 mm (#50):	11	14
0.15 mm (#100):	7	9
0.075 mm (#200):	4.7	5.6
Binder Content (Pb):	4.9	4.9
Eff. Binder Content (Pbe):	4.3	4.3
Dust-to-Binder Ratio:	1.1	1.3
Rice Gravity (Gmm):	2.549	2.546
Avg. Bulk Gravity (Gmb):	2.447	2.467
Avg Air Voids (Va):	4.0	3.1
Agg. Bulk Gravity (Gsb):	2.715	2.712
Avg VMA:	14.0	13.5
Avg. VFA:	72	77

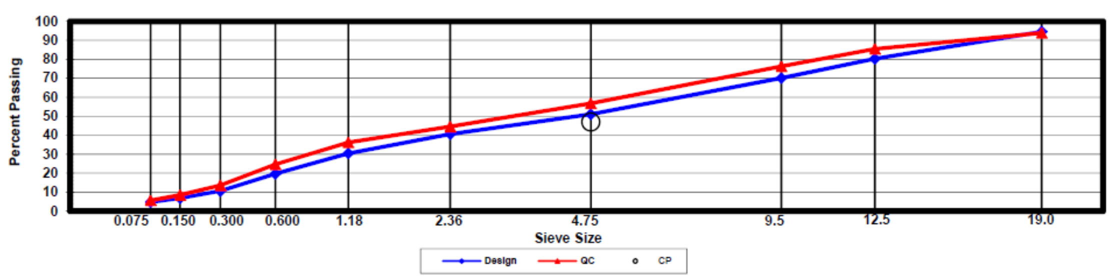
Construction Diary

Relevant Conditions for Construction

Completion Date:	August 22, 2012
24 Hour High Temperature (F):	89
24 Hour Low Temperature (F):	69
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	2.3
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	4.8
78 Opelika Limestone	35.0
57 Opelika Limestone	15.0
Shorter Coarse Sand	20.0
EAP Unfractionated RAP	25.0
Wedowee PC-RAS	5.0
Evotherm Q1	0.5
As-Built Sublot Lift Thickness (in):	2.4
Total Thickness of All 2012 Sublots (in):	6.0
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.05
Approx. Avg. Temperature at Plant (F):	280
Avg. Measured Mat Compaction:	94.0%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: S
Section: 6
Sublot: 3

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	76-22
Modifier Type:	SBS
Aggregate Type:	Lms/RAP/Sand/Grn
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	97
19 mm (3/4"):	95	93
12.5 mm (1/2"):	81	84
9.5 mm (3/8"):	72	78
4.75 mm (#4):	55	60
2.36 mm (#8):	44	48
1.18 mm (#16):	33	39
0.60 mm (#30):	21	27
0.30 mm (#50):	11	15
0.15 mm (#100):	7	9
0.075 mm (#200):	4.7	5.9
Binder Content (Pb):	5.4	5.3
Eff. Binder Content (Pbe):	4.8	4.8
Dust-to-Binder Ratio:	1.0	1.2
Rice Gravity (Gmm):	2.520	2.530
Avg. Bulk Gravity (Gmb):	2.470	2.487
Avg Air Voids (Va):	2.0	1.7
Agg. Bulk Gravity (Gsb):	2.703	2.714
Avg VMA:	13.4	13.2
Avg. VFA:	85	87

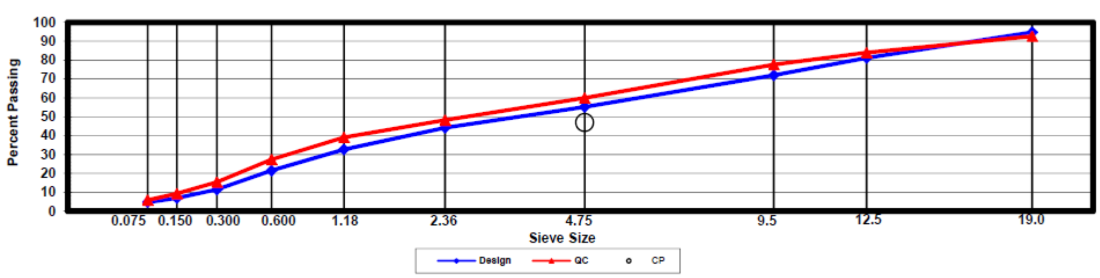
Construction Diary

Relevant Conditions for Construction

Completion Date:	August 17, 2012
24 Hour High Temperature (F):	89
24 Hour Low Temperature (F):	70
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	2.5
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	5.3
78 Opelika Limestone	21.0
57 Opelika Limestone	24.0
M10 Columbus Granite	10.0
Shorter Coarse Sand	20.0
EAP Unfractionated RAP	25.0
Green Foam	2.0
As-Built Sublot Lift Thickness (in):	2.3
Total Thickness of All 2012 Sublots (in):	6.0
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NA
Undilluted Target Tack Rate (gal/sy):	NA
Approx. Avg. Temperature at Plant (F):	285
Avg. Measured Mat Compaction:	96.5%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: S
Section: 13
Sublot: 1

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	SMA
Compactive Effort:	80 gyrations
Binder Performance Grade:	ARB12(-30)
Modifier Type:	GTR
Aggregate Type:	Granite/Flyash
Design Gradation Type:	SMA

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	100	100
12.5 mm (1/2"):	100	100
9.5 mm (3/8"):	100	100
4.75 mm (#4):	55	58
2.36 mm (#8):	25	26
1.18 mm (#16):	18	20
0.60 mm (#30):	15	17
0.30 mm (#50):	12	14
0.15 mm (#100):	10	11
0.075 mm (#200):	8.6	8.5
Binder Content (Pb):	6.4	5.7
Eff. Binder Content (Pbe):	6.0	5.2
Dust-to-Binder Ratio:	1.4	1.6
Rice Gravity (Gmm):	2.433	2.456
Avg. Bulk Gravity (Gmb):	2.336	2.375
Avg Air Voids (Va):	4.0	3.3
Agg. Bulk Gravity (Gsb):	2.648	2.645
Avg VMA:	17.3	15.3
Avg. VFA:	77	78

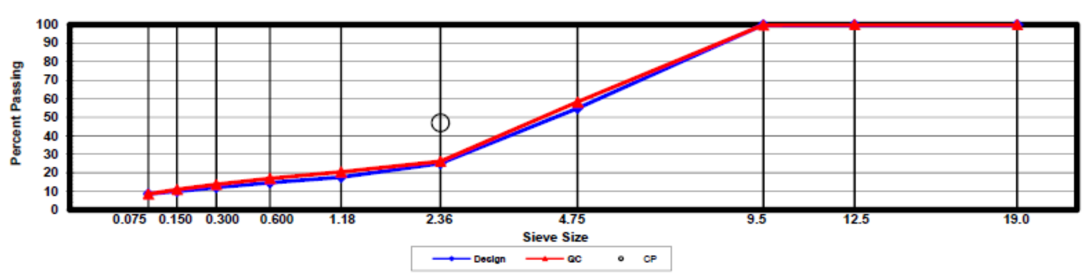
Construction Diary

Relevant Conditions for Construction

Completion Date:	September 7, 2012
24 Hour High Temperature (F):	92
24 Hour Low Temperature (F):	72
24 Hour Rainfall (in):	0.19
Planned Subot Lift Thickness (in):	1.3
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	5.4
89 Columbus Granite	79.0
M10 Columbus Granite	15.0
Evotherm Q1	0.5
Flyash	6.0
As-Built Sublot Lift Thickness (in):	1.2
Total Thickness of All 2012 Sublots (in):	6.4
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.05
Approx. Avg. Temperature at Plant (F):	275
Avg. Measured Mat Compaction:	92.9%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: S
Section: 13
Sublot: 2

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	Super
Compactive Effort:	80 gyrations
Binder Performance Grade:	ARB12(-30)
Modifier Type:	GTR
Aggregate Type:	Lms/RAP/Sand
Design Gradation Type:	ARZ

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	97	96
12.5 mm (1/2"):	88	87
9.5 mm (3/8"):	78	81
4.75 mm (#4):	56	60
2.36 mm (#8):	42	46
1.18 mm (#16):	32	36
0.60 mm (#30):	21	25
0.30 mm (#50):	12	13
0.15 mm (#100):	7	8
0.075 mm (#200):	5.0	5.2
Binder Content (Pb):	4.7	4.8
Eff. Binder Content (Pbe):	4.1	4.3
Dust-to-Binder Ratio:	1.2	1.2
Rice Gravity (Gmm):	2.550	2.538
Avg. Bulk Gravity (Gmb):	2.448	2.445
Avg Air Voids (Va):	4.0	3.6
Agg. Bulk Gravity (Gsb):	2.705	2.700
Avg VMA:	13.7	13.8
Avg. VFA:	71	74

Construction Diary

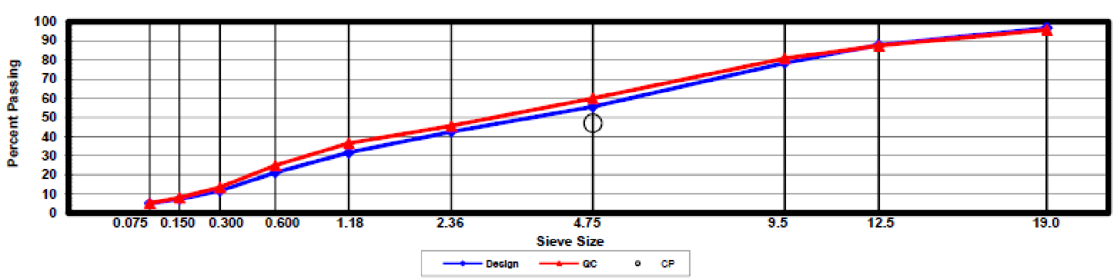
Relevant Conditions for Construction

Completion Date:	September 6, 2012
24 Hour High Temperature (F):	74
24 Hour Low Temperature (F):	73
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	3.0
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	4.8
78 Opelika Limestone	27.0
57 Opelika Limestone	17.0
Shorter Coarse Sand	21.0
EAP Unfractionated RAP	35.0
Green Foam	2.0

As-Built Sublot Lift Thickness (in):	3.2
Total Thickness of All 2012 Sublots (in):	6.4
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.05
Approx. Avg. Temperature at Plant (F):	280
Avg. Measured Mat Compaction:	94.4%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate

3/19/2013

Quadrant: S
Section: 13
Sublot: 3

Laboratory Diary

General Desccription of Mix and Materials

Design Method:	AZ
Compactive Effort:	75 blows
Binder Performance Grade:	AZ20(-16)
Modifier Type:	GTR
Aggregate Type:	Lms/Sand/Hyd Lime
Design Gradation Type:	GAP

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	100	100
12.5 mm (1/2"):	98	94
9.5 mm (3/8"):	80	80
4.75 mm (#4):	31	39
2.36 mm (#8):	14	15
1.18 mm (#16):	10	11
0.60 mm (#30):	7	8
0.30 mm (#50):	4	5
0.15 mm (#100):	3	4
0.075 mm (#200):	2.4	3.4
Binder Content (Pb):	7.7	7.2
Eff. Binder Content (Pbe):	7.0	6.5
Dust-to-Binder Ratio:	0.3	0.5
Rice Gravity (Gmm):	2.498	2.493
Avg. Bulk Gravity (Gmb):	2.361	2.389
Avg Air Voids (Va):	5.5	4.2
Agg. Bulk Gravity (Gsb):	2.774	2.750
Avg VMA:	21.7	19.4
Avg. VFA:	74	78

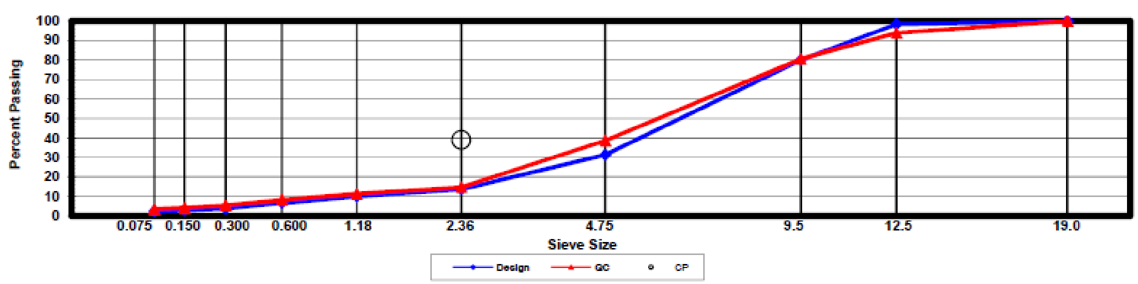
Construction Diary

Relevant Conditions for Construction

Completion Date:	September 5, 2012
24 Hour High Temperature (F):	88
24 Hour Low Temperature (F):	73
24 Hour Rainfall (in):	0.03
Planned Subot Lift Thickness (in):	1.8
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	7.8
78 Opelika Limestone	92.0
Shorter Coarse Sand	7.0
Evotherm Q1	0.5
Hyd Lime	1.0
As-Built Sublot Lift Thickness (in):	2.0
Total Thickness of All 2012 Sublots (in):	6.4
Approx. Underlying HMA Thickness (in):	0.0
Type of Tack Coat Utilized:	NA
Undilluted Target Tack Rate (gal/sy):	NA
Approx. Avg. Temperature at Plant (F):	300
Avg. Measured Mat Compaction:	92.3%



General Notes:
1) Mixes are referenced by quadrant (E=East, N=North, W=West, and S=South), section # (sequential) and sublot (top=1);
2) SMA and OGFC refer to stone matrix asphalt and open-graded friction course, respectively; and
3) Mixes not containing hydrated lime were run with either Gripper X antistrip or Evotherm Q1 warm mix additive at a 0.5% rate