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Laboratory and field evaluation of hot mix asphalt with high contents of reclaimed asphalt pavement

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LABORATORY AND FIELD EVALUATION OF HOT MIX ASPHALT WITH HIGH CONTENTS OF RECLAIMED ASPHALT PAVEMENT

by

Clinton Isaac Van Winkle

A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Civil and Environmental Engineering (Transportation) in the Graduate College of The University of Iowa

December 2014

Thesis Supervisor: Professor Hosin "David" Lee

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Clinton Isaac Van Winkle

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Civil Engineering and Environmental Engineering (Transportation) at the December 2014 graduation

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To everyone that has been a part of my life and to everyone that will, with special thanks to my parents and mentors

.....Make the best quality of goods possible at the lowest cost possible.....

-Henry Ford

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ABSTRACT

In an attempt to conserve natural resources such as materials and energy there is a trend to increase the amount of recycled asphalt pavement in asphalt pavement construction. Currently in Iowa, the amount of RAP materials allowed for the surface layer is limited to 15% by weight. The objective of this project was to develop quality standards for inclusion of RAP content higher than the current limit in asphalt mixtures. In order to determine the effects of higher RAP content it was decided that three different test sections of 30%, 35% and 40% RAP would be constructed on Highway 1 in the southern region of Iowa City, Iowa. As expected, during the design process it was determined that the RAP stockpile contained too much fine material to meet all of Superpave's design standards. In an attempt to meet all of these standards it was determined that the RAP would need to be fractionated. An extensive sieve-by-sieve analysis was performed in order to evaluate what size of screen to separate the material. This sieve-by-sieve analysis revealed an optimal sieve size to separate the fines.

The construction process was completed and three field test sections were constructed. The construction process was monitored and samples were collected for moisture susceptibility, binder grading, and field densities. A fourth test was established to be by visual inspection of the pavement periodically as it aged. Some of the field mixtures collected from test sections were compacted in the laboratory in order to test the moisture sensitivity using a Hamburg Wheel Tracking Device which determined to show no significant susceptibility. Predictably the binder extraction and performance grading showed stiffening of the binder. The field cores were taken from the various mix designs to determine the percent density of each test section, all though the average was within

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the target range for each test strip the percent within limits was less than 100%. Finally a condition survey of the test sections was performed and showed promising short-term performance for the high RAP test sections.

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INTRODUCTION

In 2008, the NAPA set a goal to double the national average RAP content from 12 percent to 24 percent in the next five years (1). Recycled asphalt pavement (RAP) is already the world's most recycled product and has been used for many years in the United States. The use of RAP makes both economic and environmental sense. RAP is a byproduct of road rehabilitation and replaces the cost of virgin binder and aggregates. Environmentally it reduces the consumption of natural resources and energy. However, the amount of RAP allowed in mix designs is still limited due to the perceived quality that a road made with a high quantity of RAP produces. It is true that the quality of the binder and aggregates in RAP are not the same as those that are of their virgin counterparts. The binder has been exposed to the elements causing oxidation which makes the binder less ductile. Similarly, the aggregates have been weathered through the paving process, exposed to traffic and then milled, all this has caused them to degrade (2). Therefore agencies such as the Iowa Department of Transportation (IDOT) has put limits on the amount of RAP that may be incorporated into a mix design.

Problem Statement

In order to provide high quality transportation infrastructure to the public at a minimal cost, road construction needs pavements that are safe, reduce material requirements, and minimizes energy usages. In addition to these three the pavement should also not be discouraging to users. RAP is seen as a way to decrease material and energy costs all while maintaining the same level of safety and comfort. Right now, the Iowa

Department of Transportation (DOT) allows a maximum of 15% RAP in the surface course without special restrictions. While 15% RAP insures a quality pavement some studies have shown that RAP percentages of up 40% perform just as well if not better than current pavements. If the Iowa DOT continues to limit the amount of RAP lower than is necessary to provide a quality pavement, they will be costing taxpayers large amounts of money in material and energy costs. Providing proof to transportation agencies that higher RAP standards will provide a resilient pavement while decreasing cost is paramount in the ability of contractors to use higher amounts of RAP in asphalt pavements.

Objective and Methodology

It is the objective of this paper to determine the maximum amount of RAP that can be incorporated into a mix design without sacrificing the integrity of the pavement. In order to accomplish this three test strips where constructed with varying percentages of RAP. Laboratory tests and field observations were then completed to determine the highest percentage of RAP performed adequately. In the laboratory a Hamburg wheel tracking device was used to determine the susceptibility to moisture, and the binder was graded to determine the effect of aged binder on the virgin binder. From the field, cores were drilled and tested to determine the density. Along with the densities, the pavement was and will continue to be evaluated for defects as it ages.

LITERATURE REVIEW

The state of Iowa has adopted the mix design process called Superpave, which selects binder grade based on its own asphalt performance grading (PG) system. PG grading is based on the expected low and high extremes in the area and is measured in 6° C increments. For example an asphalt binder with a PG grade of 58 -22 would be suitable for an extreme 7-day average high air temperature of 58°C and a one day low temperature of -22° C. The next higher PG grade would be 64 -16.

Due to oxidization, the binder found in RAP is usually stiffer and therefor has a higher PG grade for both extremes. When the oxidized binder from RAP is combined with virgin binder it changes the PG grade to something in-between the PG grades of the new and aged binder. It is assumed that the proportion of asphalt binder that comes from RAP can approach 20% without changing the prescribed standard asphalt grade to be used. When more than 20% of the binder originates from a RAP source, testing of the RAP's recovered binder is recommended in combination with blending charts to determine what performance grade of virgin binder should be used (2). In extreme cases viable mixes with RAP contents of up to 50% have been designed (3).

It was reported that the addition of RAP has raised the high temperature grading of the combined binder by one to two grades but, based on fatigue, rutting and TSR tests, there was no significant difference in performance between high RAP mixes (between 21% and 30% by binder replacement) and a low RAP mixes (20% or less by binder replacement) (4).

Mixing of Virgin Binder with Aged Binder

There is a lack of understanding about how the binder from the RAP contributes to the overall mix. Viewpoints range from the RAP binder completely blends with the virgin binder to that it does not blend at all (i.e., RAP acts in the mix like a "black rock"). The Illinois DOT assumes 100% contribution for the residual asphalt binder from the RAP which reduces the requirement for virgin asphalt binder by the full amount of asphalt binder in the RAP. However, this assumption has been reported to be inaccurate and thus could result in an erroneous Hot Mix Asphalt (HMA) job mix formula causing dry HMA (5). Several studies have shown the contribution of RAP binder is somewhere in between these two theories by examining the rheology of the resulting binder (6, 7, 8).

Agency Limits on Recycled Asphalt Pavement

Most agencies limit the quantity of RAP materials in asphalt mixtures and/or the amount of recycled binder. For example, Iowa DOT limits the use of RAP materials up to 15% for the surface course while at least 70% of the total asphalt binder shall be virgin asphalt. A contractor is allowed to use more than 15% when there is quality control sampling and testing of the RAP materials meeting the requirements in the specification (9). It has been reported that mixes with up to 40% RAP materials have performed better than mixes with 20% RAP materials in Hamburg Wheel Tracking Test and others (10, 11). DOTs that limit the amount of recycled binder rather than the quantity of RAP tend to allow higher RAP percentages by weight of the total mixture. It is important to understand that RAP has a higher amount of small particles which makes it is difficult to meet the mix design criteria.

Fractionation of Recycled Asphalt Pavement

Fractionation of RAP (FRAP) is the act of separating RAP stockpiles by particle size. The most common method of fractionation is by running the material over a sieve. Recently, agencies have been successful in utilizing as much as 50% FRAP materials. Because FRAP materials include less fine materials, it is feasible to produce mixtures that would meet Superpave mix design requirements. For example, the Wisconsin DOT requires at least 80% of the total asphalt binder shall be virgin when the RAP is used but it may be reduced to 75% when FRAP is used. A contractor may further reduce a percentage of virgin binder below 75% if he/she can furnish test results indicating the resultant binder meets the originally specified grade (12). One example of high RAP being used across the United States is the binder course of the Florida State Road 15A. It was successfully constructed using asphalt mixtures containing 45 percent FRAP (13). Another location is in Kansas, where the DOT limits the use of RAP to 20-25% without binder modification. A final example would be on Overland Park's Antioch Road with a high volume of traffic, 35% FRAP has been incorporated in a Superpave surface mix design (14).

Classifications of Recycled Asphalt Pavement Material in Iowa

The IDOT has adopted the categorization system that classifies RAP stockpiles into three types: classified RAP, certified RAP and unclassified RAP. Each classification is determined by if its origin is traceable, the quality of its aggregates, how it was stockpiled, and if it meets a specified gradation (15). The maximum RAP percentage allowed in surface course mixtures is limited by its RAP stockpile type, which is to be further reduced for higher ESAL pavements. As can be seen from Table 1, a surface layer can have a maximum of 15% classified RAP, an allowed maximum of 10% certified RAP for low-volume roads with less than or equal to 300,000 ESAL's, and no unclassified RAP materials can be used on surface mixes.

Classified RAP	Certified RAP	Unclassified RAP	
Requirements	Requirements	Requirements	
- Documented Source	- Undocumented Source	- Undocumented Source	
- High Aggregate Quality	- Lower Aggregate Quality	- Unknown/Poor Aggregate	
- Stockpiled Separately	- Poor Stockpiling	- Poor Stockpiling	
- Meets Quality Control	- Meets Quality Control	- No Quality Control	
Allowable Usage	Allowable Usage	Allowable Usage	
-15% weight in surface	-10% surface < 300K ESAL	- 0% surface for all ESAL	
-Min. 70% virgin AC	-20% Interm. <u><</u> 1M ESAL	- 10% Interm. ≤ 1M ESAL	
-No limit in other layers	-20% Base for all ESAL	- 10% Base for all ESAL	

 Table 1: Iowa DOT RAP Stockpile Categorization Criteria and Allowable Usage

Superpave Mix Design

In 1983 the Strategic Highway Research Program completed Superpave Mix Design Method as a way to improve materials selection. Superpave has multiple steps including; aggregate selection, asphalt binder selection, sample preparation, density and voids calculations, and optimum asphalt binder content selection. Aggregate selection places restrictions on the gradation and consensus requirements (i.e. angularity, clay content). The next step is selecting the performance grade of the binder, which is done by predicting the maximum and minimum pavement temperatures. Then samples are prepared with different percentages of binder, they are tested and a graph is made to determine the optimal percentage of binder. After this the density and voids analysis determines the volumetric parameters. Finally the optimum asphalt binder content is derived by compacting a sample a set number of times to yield a target amount of air voids of 4%. (16)

Superpave Binder Performance Grading

Performance grading (PG) is based on the idea that binders should be specific to the minimum and maximum temperatures that the pavement will reach. Superpave PG will come with two numbers one for the average seven-day maximum pavement temperature and the other the minimum pavement temperature the pavement will experience measured in six degree Celsius increments. For example a typical binder grade might be a PG 64 -28. To determine the PG for a binder there are two test the Dynamic Shear Rheometer for the high temperature and the Bending Beam Rheometer for the low. (17)

Hamburg Wheel Tracking Device

The Hamburg Wheel Tracking Device (HWTD) was developed in Germany to evaluate rutting and stripping potential. This device tracks a loaded steel wheel over a compacted specimen all while submersed in heated water. The amount of deflection is measured over twenty thousand passes. From a graph plotting deflection verses number of passes there are two things to make note. The first is the amount of deflection over time and the second is the development of an inflection point. While a slow deflection in the graph is an indication of the long term performance of the pavement. The more important indicator is the development of an inflection point because this is an indication of failure between the binder and the aggregates. (18)

Air Voids

It has long been determined that the amount of voids in asphalt pavement has a significant effect on the quality of the pavement. High air voids that are too high or too low can cause a variety of problems such as raveling, rutting, and moisture damage all or which decrease strength and reduce fatigue life. The air voids in a pavement is said to be low if the percent air is less than 3%, and conversely if air voids are greater than 8% they are said to be too high. (19)

DESIGN OF HIGHWAY 6 HIGH RAP TEST STRIPS

On the south side of Iowa City runs a four lane Highway that is at times both Highway 6 and Highway 1. This road was constructed of concrete and was in poor repair, the City of Iowa City let a project to have this road reconstructed joints repaired, lay a 1.5" intermediate layer and a 1.5" surface layer over the top of the damaged concrete. LL Pelling is an asphalt paving contractor based out of North Liberty, won the bid. Through LL Pelling and the University of Iowa and with the permission of the City of Iowa City a decision was made to construct three test strips with varying percentages of RAP.

The Recycled Asphalt Pavement Material

In order to be used in a surface mix the RAP stockpile needed to be classified which means that the source needed to be documented, the aggregates needed to be of high quality, while the stockpile needed to be kept separate, and meet quality control standards. Each of these requirements were met by a stockpile from an Interstate 80 (I-80) resurfacing project that LL Pelling had completed a year prior to the HWY1/Hwy 6 Resurfacing project. In addition to being classified the stockpiled RAP were milled at a low depth and a high speed to reduce the dust content. Due to these reclaiming practices, the stockpile sample had a relatively low dust content of 10.7% which eased the amount of fractionation.

Fractionation of Recycled Asphalt Pavement Material

To determine what size of fractionation was necessary for the I-80 RAP a determination of the size of the aggregates in the RAP needed to be assessed. To do this

the designers needed to get a better understanding of what size of aggregates were in each size of RAP. A sample of I-80 RAP was separated into different sizes by sieves then each sieve was put through what is called in the industry a "burn off". A "burn off" is another name for AASHTO T 308 or ASTM D 6307 this test places the sample into an ignition oven which burns the asphalt off of the aggregates to determine how much asphalt is in each sample size. The aggregates can then be tested using a sieve by sieve analysis to determine the amount of each size of aggregate in each size of RAP. The results from each size of I-80 RAP can be seen in Table 2. From the table it can be seen that the percentage of dust is significantly higher on the #4 sieve and lower. Therefor the fractionation screen was selected to 5/16" so that the 3/8" particles could be salvaged but still allow for the ease of segregation of everything #4 and smaller.

~	Recovered Aggregate Composition After Ignition Oven Burn-Off –									%				
Size of					(%	Retain	ned)					Asphalt	% of	% of Dust
RAP	3/4"	1/2"	3/8"	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	Pan	Content	Stockpile	Content
1 1/2"	0.0	3.9	4.7	27.5	20.1	13.9	9.6	7.6	3.8	1.4	7.6	4.66	4.15	3.30
1"	0.0	5.5	5.7	27.7	18.8	12.8	8.7	7.6	3.8	1.4	8.0	4.78	5.54	4.61
3/4"	1.1	1.1	10.0	6.2	27.6	16.2	10.9	8.3	7.8	3.7	7.2	4.61	6.41	4.79
1/2"		20.8	10.6	20.8	13.6	9.6	7.0	6.2	3.3	1.2	7.0	4.09	12.68	9.26
3/8"			39.81	21.9	10.2	7.2	5.2	5.0	2.7	1.0	5.7	3.62	8.62	5.11
No. 4				56.1	15.8	7.2	5.4	5.3	2.8	1.0	5.4	3.66	22.18	14.91
No. 8					65.2	12.0	5.5	5.7	3.1	1.1	7.5	4.43	15.56	12.13
No. 16						61.7	13.6	7.4	3.9	1.6	11.8	5.55	10.38	12.82
No. 30							60.8	14.9	5.0	1.9	17.4	6.72	6.12	11.13
No. 50								67.2	7.4	2.5	23.0	7.98	4.35	10.45
No. 100									64.2	7.5	28.3	9.34	2.08	6.15
No. 200										57.2	42.8	9.74	0.98	4.37
Normalized Composite	0	3	6	20	20	14	10	9	5	2.1	9.6	4.75	99.1%	99.1%
Binder Extraction	0	2	5	21	20	14	11	10	4	2.3	10.7	4.00		
Estimated Coarse RAP	0	5	10	34	16	10	7	6	4	1.4	6.7	4.02	59.6%	42.0%
Estimated Fine RAP	0	0	0	0	26	21	15	14	7	3.2	13.8	5.86	40.4%	58.0%

 Table 2: Sieve-Size-Separated RAP Material Composition Analysis

High Recycled Asphalt Pavement Mix Designs

Mix designs for each test strip were performed for a 10 million ESAL 1/2" mix with a target of 30%, 35% and 40% FRAP materials. An initial step in the mix design process is the selection of the binder and in this case a PG 70-22 binder was selected for the conventional pavement on this road. It is known that the binder in the RAP contributes significantly to the mix and, due to a high RAP content, a softer PG 64-28 binder was adopted for the proposed test section mixes with a high RAP content (20). Percent binder replacements by RAP materials were calculated as 20.1%, 24.7% and 29.0% using the following formula:

Percent Binder Replacement

$$= \frac{(\% of Binder Content in RAP \times \% of RAP in Mix)}{Total \% of Binder in the Mix} \times 100$$

High Recycled Asphalt Pavement Mix Design Results

Table 3 summarizes the volumetric design criteria for the HMA 10 million ESAL 1/2" surface mixtures designed for this study. Volumetric properties are calculated at the optimum binder content of each mix and compared against these mix design criteria. The proportions were then determined for each mix and can be seen in Table 4.

Mixture Property	Design Air Voids P _a (%)	Voids Filled w/ Asphalt VFA (%)	Voids in Aggregate VMA (%)	Film Thickness (µm)	Dust-Binder Ratio D:B	Maximum Dust Content (% -No. 200)
DOT Spec.	4.0	70 - 80	Min. 14.0	8.0 - 13.0	0.6 - 1.4	10.0

Table 3: Volumetric Mix Design Criteria

Material	29.0% RAP	34.0% RAP	38.0% RAP	Producer/ Location	Gsb	% Abs
Sand	14.0%	11.0%	11.0%	Williams/ S&G Materials Inc	2.634	0.47
TAT4 Manufactured Sand	20.0%	20.0%	14.0%	Klein/ River Products Co	2.649	0.84
3/8" Chips	15.0%	15.0%	12.0%	Columbus Junction/ River Products Co	2.583	3.23
3/4" Chips	10.0%	8.0%	11.0%	Klein/ River Products Co	2.652	0.86
3/8" Slag	12.0%	12.0%	14.0%	Montpelier/ Blackheart Slag	3.709	1.2
RAP	29.0%	34.0%	38.0%	ABC13-0119 (3.38% AC)	2.662	1.3

Table 4: Mix Design Summary

*Binder 64-28 Bituminous Material & Supply (Tama, IA)

Both the design and actual percentages of RAP by weight, optimum total binder contents, optimum virgin binder contents, and percentages of RAP by binder replacement as can be seen in Table 5. First, the optimum total binder content was calculated for each mix. Then the amount of binder from FRAP was estimated and the remaining amount of virgin binder was computed. Finally, the percentage of FRAP by binder replacement was calculated. It should be noted that due to a difficulty in weighing exact percentages of FRAP at the asphalt plant, actual percentages of FRAP used for building the test sections were slightly increased.

	29% R	AP by	34% R	AP by	38% RAP by		
	weight		wei	ght	weight		
	Design	Actual	Design	Actual	Design	Actual	
% FRAP by Weight	29%	30.0%	34%	35.5%	38%	39.2%	
Optimum Total AC	4.70%	4.80%	4.50%	4.49%	4.30%	4.38%	
Optimum Virgin AC	3.70%	3.82%	3.40%	3.33%	3.10%	3.10%	
% FRAP by Binder	20.1%	20.4%	24.7%	25.9%	29.0%	29.3%	

Table 5: Percent RAP by Weight and by Binder Replacement

Similarly in Table 6, a summary of the mix design results for high RAP mixes with actual amounts of FRAP of 30.0% by weight (20.4% by binder replacement), 35.5% by weight (25.9% by binder replacement) and 39.2% by weight (29.3% by binder replacement). For each mix design, the optimum binder content was determined to produce 4% air voids for the 10 million ESAL 1/2" HMA mix. The volumetric properties of each mixture were determined at the optimum binder content and VMA, VFA, combined aggregate gradation, film thickness and dust-binder ratio were analyzed for each mix design.

Actual % FRAP by Weight	30.0%	35.5%	39.2%
% FRAP by Binder	20.4%	25.9%	29.3%
Optimum AC Content	4.80%	4.49%	4.38%
Max. Sp. Gr. (G _{mm})	2.565	2.578	2.609
Core Sp. Gr. (G _{mb})	2.497	2.507	2.549
Binder Sp. Gr. (G _b)	1.0183	1.0191	1.0196
Agg. Sp. Gr. (Gsb)	2.734	2.735	2.754
Water Absorp. (% Abs)	1.325	1.358	1.313
Effective Sp. Gr. (G _{se})	2.778	2.778	2.81
Aggregate Surface Area	4.39	4.57	4.45
% Binder Abs. (P _{ba})	0.59	0.58	0.71
Effective Binder (Pbe)	4.24	3.94	3.67
Mix Design Criteria			
VMA (%)>14	13	12.5	11.5
70 <vfa (%)<80<="" td=""><td>79.6</td><td>78.0</td><td>80.0</td></vfa>	79.6	78.0	80.0
Dust Content<10	3.8	4.2	4.4
8 <film td="" thick<13<=""><td>9.7</td><td>8.6</td><td>8.2</td></film>	9.7	8.6	8.2
0.6 <db ratio<1.4<="" td=""><td>0.92</td><td>1.14</td><td>1.2</td></db>	0.92	1.14	1.2

 Table 6: Volumetric Mix Design Results from Mixtures Used for Construction

Construction

Figure 1 shows the layout of the test sections. They are located on the westbound inside lanes of Highway 6 from approximately Lakeside Drive to Sycamore Street. Each test section is a 1.5-inch thick surface layer that extends roughly 0.35 mile. The actual amounts of FRAP materials were 30.0% (29% design), 35.5% (34% design) and 39.2% (38% design). All sections were constructed over the top of a 1.5-inch thick intermediate layer with a PG binder of 72-34 on the night September 8, 2013. The 30.0% FRAP section starts at Lakeshore Dr. and ends at Fairmeadows Boulevard, the 35.5% FRAP section starts at Fairmeadows Boulevard and ends at Sycamore Street and the 39.2% FRAP section starts at the Sycamore Street and ends at Broadway Street. The traffic level for test sections is approximately 13,100 ADT.



FIGURE 1: Layout of test sections.

Volumetric mix design results are plotted in Figure 2. The fractionation method was effective in reducing the amount of fine aggregates from the original stockpile and thereby

improving volumetric properties. These volumetric properties of mixtures were influenced by the optimum asphalt content of each mixture. Although the fractionation procedure reduced the amount of fine aggregate and dust content, mix designs exhibited lower optimum asphalt contents than the regular HMA mixtures. The improvement of a mixture's volumetric properties was often offset by the lower optimum asphalt content resulting in a lower asphalt film thickness and a high dust-binder ratio. The dust content was relatively low in the original RAP stockpile and, as can be seen from Figure 2, the mix designs met all of the Superpave mix design criteria except for VMA.





(a) Voids in the Mineral Aggregate (VMA)



(c) Dust Content



(e) Dust to Binder Ratio

(f) Optimum Asphalt Cement Content

FIGURE 2: Volumetric mix design criteria.

(b) Voids Filled with Asphalt (VFA)



(d) Film Thickness



EVALUATION OF HIGH RECYCLED ASPHALT PAVEMENT MIX DESIGNS

There are four tests that were performed on the test strips to determine the quality of the pavement; Pavement Density on the paved test strips, Performance Grading of the extracted binder, Hamburg Wheel Tracking Device on samples taken from the truck, and a Pavement Condition Survey of the constructed pavement. The density of the pavement was measured to identify any inconsistencies between RAP percentages. Performance Grading of the extracted binder was conducted to determine the effect of higher amounts of RAP on the total binder content. While, the Hamburg Wheel Tracking Device was implemented to determine durability when exposed to water. Finally, throughout the life of the pavement observation will take place to evaluate the overall condition of the pavement.

Laboratory Evaluation of Field Mixtures

Performance Grading

To identify the effect of FRAP on the rutting potential of the virgin asphalt binder of PG 64-28, a Dynamic Shear Rheometer (DSR) test was performed on the asphalt binder extracted from field mixtures with 30.0%, 35.5% and 39.2% FRAP. As shown in Figure 3, the extracted binders from field mixtures with 30.0%, 35.5% and 39.2% FRAP met the minimum G*/sin delta value of 1 kPa for high temperatures of 76 °C, 76 °C, and 82 °C respectively. These high temperatures are two or three levels higher than the high

temperature of 64 °C for the virgin binder of PG 64-28. This result confirms that the similar level of stiffening in the original binder occurred due to 30.0% and 35.5% FRAP but more significant stiffening occurred with 39.2% FRAP.



FIGURE 3: |G*| / sin (delta) vs temperature.

To identify the effect of FRAP on the low-temperature cracking potential of the PG 64-28 virgin asphalt binder, the Bending Beam Rheometer (BBR) test was performed on asphalt binder extracted from field mixtures with 30.0%, 35.5% and 39.2% FRAP. As summarized in Table 7, the extracted binders from field mixtures with 30.0%, 35.5% and 39.2% FRAP met the minimum m-value of 0.3 and maximum stiffness value of 300 MPa for the low test temperatures of -12 °C, -6 °C, and -12 °C respectively. These temperatures are one or two levels higher than the low test temperature of -18 °C of the virgin binder PG 64-28. This result confirms that the similar level of stiffening of the original binder has occurred for all FRAP contents.

Temperature	-6 °C		-12	°C	-18 °C		
Percent FRAP	Stiffness	M- Value	Stiffness	M- Value	Stiffness	M-Value	
30.0%			201	0.301	354	0.271	
35.5%	108	0.293	228	0.255			
39.2%	77.6	0.366	200	0.301			

Table 7: Bending Beam Rheometer Data

Based on both DSR and BBR test results, the PG grade of extracted binders from the field mixtures with 30.0%, 35.5% and 39.2% FRAP can be classified as PG 76-22, PG 76-16, and PG 82-22 respectively. It can be concluded that the virgin binder of PG 64-28 used to build the test sections high temperature was significantly affected by the FRAP amounts due to the aged binder from FRAP. However the low temperature grading was minimally affected.

Hamburg Wheel Tracking Device

In order to evaluate the moisture susceptibility of field mixtures with varying FRAP amounts, the Hamburg Wheel Tracking Test (HWTT) was performed following the AASHTO T324 procedure and multiple pictures of the Hamburg Wheel Tracking Device can be seen in Figure 4. HWTT applies a constant load of 685 N through a steel wheel in a water bath that is kept at 50 °C for the entirety of the test. In preparing the samples, the mixture was short-term aged for 4 hours at 135 °C (275 °F) then followed by 2 hours at the compaction temperature, 145 °C (293 °F). After this the specimens were prepared for testing by being compacted to a specific height and diameter of 61.5 mm and 150 mm

respectively. Lastly, they were conditioned at the test temperature of 50 °C for 30 minutes before the test began. Once the specimens were conditioned, the test was performed until it applied 20,000 passes or the rutting exceeded 20 mm. The stripping inflection point and stripping slope were then used to determine damage caused by moisture.



FIGURE 4: Hamburg Wheel Tracking Device and specimens ready for testing.

Figure 5 shows the HWTT results for field mixtures with 30.0%, 35.5%, and 39.2% FRAP by weight. The target air voids for each sample was 6% which can be considered as a typical field density. All specimens exhibited excellent performance with little rutting resulting in a lack of a stripping inflection point in 20,000 passes. Therefore, given the limited test data, it can be concluded than the high-RAP field mixtures are not a threat to be susceptible to moisture damage.





(c) 39.2% FRAP FIGURE 5: Hamburg Wheel Tracking Test results of high-FRAP field mixtures.

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Field Evaluation of Test Sections

Pavement Density

The field asphalt mixtures were sampled to determine the volumetric properties. As shown in Table 8, the average bulk-specific gravity of cores from the test sections with 30.0% FRAP, 35.5% FRAP and 39.2% FRAP were 2.446, 2.422 and 2.460, resulting in air voids of 4.7%, 6.0% and 5.7%. Since the target air voids are 6.0% +/- 2.0%, all three sections met the field density void requirement.

Table 8: Density and Air Voids of Field Cores

a. 50.070 FRAI FICH COL Data									
Core	Station	Gmb	% of Gmm	Pa (%)	Thickness (in.)				
1	268+95	2.430	94.7	5.3	1.625				
2	268+72	2.488	97.0	3.0	1.375				
3	265+07	2.448	95.4	4.6	1.375				
4	262+63	2.426	94.6	5.4	1.750				
5	259+52	2.447	95.4	4.6	1.750				
6	256+10	2.435	94.9	5.1	1.750				
Average		2.446	95.3	4.7	1.604				
Standared Deviation		0.023	0.9	0.9	0.184				

a. 30.0% FRAP Field Core Data

b. 35.5% FRAP Field Core Data

Core	Station	Gmb	% of Gmm	Pa (%)	Thickness (in.)
1	252+63	2.433	94.4	5.6	1.500
2	247+19	2.436	94.5	5.5	1.500
3	245+53	2.382	92.4	7.6	1.625
4	242+27	2.426	94.1	5.9	1.625
5	239+36	2.444	94.8	5.2	1.625
6	238+02	2.413	93.6	6.4	1.625
Average		2.422	94.0	6.0	1.583
Standared Deviation		0.022	0.9	0.9	0.065

c. 39.2% FRAP Field Core Data

Core	Station	Gmb	% of Gmm	Pa (%)	Thickness (in.)
1	234+65	2.407	92.3	7.7	1.625
2	229+88	2.467	94.6	5.4	1.750
3	229+33	2.487	95.3	4.7	1.500
4	216+40	2.441	93.6	6.4	1.500
5	213+89	2.463	94.4	5.6	1.250
6	209+39	2.493	95.6	4.4	1.250
Average		2.460	94.3	5.7	1.479
Standared Deviation		0.032	1.2	1.2	0.200

Condition Survey

To evaluate the short-term performance of the test sections, a pavement condition survey was performed on May 29, 2014, about 8 months after construction. One of the most dominant distress types was reflective joint cracking, which were typically spaced at about twenty feet intervals. This extensive transverse cracking might have been caused by a combined effect of underlying deteriorated concrete pavement joints and one of the coldest Iowa winters on record.







Length and severity of transverse cracks were measured and their results are summarized, examples of the cracks may be seen in Figure 6. When tabulating the lengths of crack a method to indicate the severity of the cracking was need. To do this a multiplier of three, two and one was used for high medium and low severity cracking, respectfully. As can be seen from Table 9, the test section with 39.2% FRAP performed the best followed by the

35.5% FRAP and 30.0% FRAP test sections. It can be concluded that as the FRAP amount is increased; the amount of transverse cracking was decreased.

Severity	30.0% FRAP (ft)	30.0% FRAP Multiplier (ft)	35.5% FRAP (ft)	35.5% FRAP Multiplier (ft)	39.2% FRAP (ft)	39.2% FRAP Multiplier (ft)
High	0	0	12	0	0	0
Medium	288	864	216	648	84	252
Low	411	411	315	315	366	366
Total	699	1275	531	963	450	618
Section Length	1841	1841	1787	1787	1787	1787
Per Sta.	38	69.3	29.7	53.9	25.2	34.6

Table 9: Transverse Cracking Developed in Three Test Sections

SUMMARY AND CONCLUSIONS

This paper discusses efforts to evaluate test sections constructed with varying amounts of RAP materials. The sieve-by-sieve analysis of classified RAP materials identified the distribution of aggregates and binder associated with RAP materials retained on each sieve. First, RAP materials were fractionated by removing fine RAP materials passing the 5/16" sieve. Mix designs were performed on mixtures with target amounts of Fractionated RAP (FRAP) materials of 30%, 35% and 40% and they passed all volumetric design criteria except VMA. It can be concluded that the fractionation is effective in improving volumetric properties of HMA mixtures with a high RAP content.

Three test sections with actual amounts of 30.0%, 35.5% and 39.2% FRAP were constructed on Highway 6 in Iowa City and the average field densities measured from the cores were 95.3%, 94.0%, and 94.3%, respectively, which met density requirement of $94\% \pm 2.0\%$. Superpave binder tests were performed to determine the binder grade of extracted binder from field mixtures with varying FRAP amounts. Based on the limited test results, it can be concluded that as the RAP material is increased, both high and low temperatures of PG grade of the asphalt binder are also increased.

Field mixtures were compacted in the laboratory to evaluate the moisture sensitivity using a Hamburg Wheel Tracking Device and rut depths after 20,000 passes were less than 3mm for all three test sections. Finally, a condition survey was performed on the test sections with varying FRAP contents to evaluate their relative performances in the 8 months after construction. The test section with 39.2% FRAP performed the best followed by 35.5% FRAP and 30.0% FRAP. It can be concluded that as the FRAP amount

is increased; the amount of transverse cracking is decreased.

Recommendations

At this time insufficient data exists to make a recommendation on what level of RAP is acceptable without sacrificing the quality of our transportation infrastructure. Currently there is no indication that these high RAP mix designs will degrade at a faster rate than there 15% counter parts. As the test sections continue to be evaluated, greater insight will be understood about the long term resiliency of each individual percentage of RAP. Providing adequate durability of the of the three RAP percentages, recommendations can then be made to raise the allowable amount of recycled asphalt pavement in pavements. Additional modifications should then be added to address the VMA in the Superpave mix design procedure.

APPENDIX A: MIX DESIGNS

Form 955r ver. 8.10

Iowa Department of Transportation

Highway Division-Office of Materials R Production Limits For Age

County :	Johnson		Project No.: STP-006-6(74)-2C	-52		Date:	09/08/13	
Project Location:	In Iowa C	ity from 50	0' N of S Jct IA 1 to Lakeside Dr		Mix Desi	gn No.:	ABC13-	5041
Contract Mix Ton	nage:	300	Course: Surface (Trave	l Lane)	Mix Size	(in.):	1/2	
Contractor:	L.L. Pelli	ng	Mix Type: HMA (1	OM ESAI	.), Surface	, 1/2, FR	ICL-3	
Material	Ident #	% in Mix	Producer & Location	Type (A or B)	Friction Type	Beds	Gsb	%Ab
Sand	A52508	14.0%	Williams/S&G Materials Inc	A	4		2.634	0.47
TAT4 M. Sand	A52006	20.0%	Klein/River Products Co	A	4	2-10	2.649	0.84
3/8"chips	A58002	15.0%	Columbus Junction/River Products Co	A	4	16-19	2.583	3.23
3/4" A	A52006	10.0%	Klein/River Products Co	A	4	2-10	2.652	0.86
3/8" Slag	A70008	12.0%	Montpelier/Blackheart Slag	A	2		3.709	1.20
RAP	Surface mi	29.0%	ABC13-0119 (3.38 % AC)	A	2	0	2.662	1.30
							1	

Material	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Sand	100	100	100	100	95	90	79	53	16	2	1
TAT4 M. Sand	100	100	100	100	98	76	43	20	8.3	2.8	2.5
3/8"chips	100	100	100	95	50	15	4	2.7	2.6	2.5	2.3
3/4" A	100	100	55	19	4	3	3	2.5	2.5	2	2
3/8" Slag	100	100	100	100	31	1.8	1.6	1.5	1.5	1.4	1
RAP	100	100	93	80	51	36	27	20	14	10	8.8

Preliminary Job Mix Formula Target Gradation

Upper Tolerance	100	100	100	92	66	46		22			6
Comb Grading	100	100	93	85	59	41	29.0	18.0	8.7	4.4	3.8
Lower Tolerance	100	100	86	78	52	36		14			1.8
S.A.sq. m/kg	Total	4.30	ana este recentu	+0.41	0.24	0.34	0.47	0.52	0.54	0.54	1.25

Production Limits for Aggregates Approved by the Contractor & Producer.

Sieve Size	14.0% Sa	of mix nd	20.0% TAT4 I	of mix M. Sand	15.0% 3/8"	of mix chips	10.0% 3/4	of mix " A	12.0% 3/8"	of mix Slag	29.0% R	of mix AP
in.	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	98.0	100.0	100.0	100.0	98.0	100.0
1/2"	100.0	100.0	100.0	100.0	98.0	100.0	48.0	62.0	100.0	100.0	86.0	100.0
3/8"	98.0	100.0	98.0	100.0	88.0	100.0	12.0	26.0	98.0	100.0	73.0	87.0
#4	88.0	100.0	91.0	100.0	43.0	57.0	0.0	11.0	24.0	38.0	44.0	58.0
#8	85.0	95.0	71.0	81.0	10.0	20.0	0.0	8.0	0.0	6.8	31.0	41.0
#30	49.0	57.0	16.0	24.0	0.0	6.7	0.0	6.5	0.0	5.5	16.0	24.0
#200	0.0	3.0	0.5	4.5	0.3	4.3	0.0	4.0	0.0	3.0	6.8	10.8

This is a revised report which includes field changes to the aggregate proportions Comments:

Copies to:

The above target gradations and production limits have been discussed with and agreed to by an authorized representative of the aggregate producer.

Producer

Signed:

Contractor

FIGURE A1: Mix design of 30.0% RAP.

Signed:

Iowa Department of Transportation Highway Division-Office of Materials

			Proportion & Production Limits For	Aggregate	6			
County :	Johnson		Project No.: STP-006-6(74)-20	:-52		Date:	09/08/13	
Project Location:	In Iowa Ci	ty from 50	00' N of S Jct IA 1 to Lakeside Dr		Mix Desi	gn No.:	ABC13-	5042
Contract Mix Ton	nage:	300	Course: Surface (Trave	el Lane)	Mix Size	(in.):	1/2	
Contractor:	L.L. Pelli	ng	Mix Type: HMA (10M ESAI	.), Surface	, 1/2, FR	ICL-3	
Material	Ident #	% in Mix	Producer & Location	Type (A or B)	Friction Type	Beds	Gsb	%Abs
Sand	A52508	11.0%	Williams/S&G Materials Inc	A	4		2.634	0.47
TAT4 M. Sand	A52006	20.0%	Klein/River Products Co	A	4	2-10	2.649	0.84
3/8"chips	A58002	15.0%	Columbus Junction/River Products Co	A	4	16-19	2.583	3.23
3/4" A	A52006	8.0%	Klein/River Products Co	A	4	2-10	2.652	0.86
3/8" Slag	A70008	12.0%	Montpelier/Blackheart Slag	A	2		3.709	1.20
RAP	Surface mi	34.0%	ABC13-0119 (3.38 % AC)	A	2	0	2.662	1.30
Type and Source of	Asphalt Bir	der:	64-28 Bituminous Matr'l	& Supply (1	'ama, IA)	L	l	L

Material	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Sand	100	100	100	100	95	90	79	53	16	2	1
TAT4 M. Sand	100	100	100	100	98	76	43	20	8.3	2.8	2.5
3/8"chips	100	100	100	95	50	15	4	2.7	2.6	2.5	2.3
3/4" A	100	100	55	19	4	3	3	2.5	2.5	2	2
3/8" Slag	100	100	100	100	31	1.8	1.6	1.5	1.5	1.4	1
RAP	100	100	93	80	51	36	27	20	14	10	8.8

Preliminary Job Mix Formula Target Gradation

Upper Tolerance	100	100	100	93	66	45		21			6
Comb Grading	100	100	94	86	59	40	28.0	17.0	8.9	4.8	4.2
Lower Tolerance	100	100	87	79	52	35		13			2.2
S.A.sq. m/kg	Total	4.44		+0.41	0.24	0.33	0.45	0.50	0.55	0.59	1.37

Production Limits for Aggregates Approved by the Contractor & Producer.

Sieve Size	11.0% Sa	of mix nd	20.0% TAT4 !	of mix M. Sand	15.0% 3/8"	of mix chips	8.0% 3/4	of mix " A	12.0% 3/8"	of mix Slag	34.0% R	of mix AP
in.	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	98.0	100.0	100.0	100.0	98.0	100.0
1/2"	100.0	100.0	100.0	100.0	98.0	100.0	48.0	62.0	100.0	100.0	86.0	100.0
3/8"	98.0	100.0	98.0	100.0	88.0	100.0	12.0	26.0	98.0	100.0	73.0	87.0
#4	88.0	100.0	91.0	100.0	43.0	57.0	0.0	11.0	24.0	38.0	44.0	58.0
#8	85.0	95.0	71.0	81.0	10.0	20.0	0.0	8.0	0.0	6.8	31.0	41.0
#30	49.0	57.0	16.0	24.0	0.0	6.7	0.0	6.5	0.0	5.5	16.0	24.0
#200	0.0	3.0	0.5	4.5	0.3	4.3	0.0	4.0	0.0	3.0	6.8	10.8

Comments: This is a revised report which includes field changes to the aggregate proportions

Copies to:

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The above target gradations and production limits have been discussed with and agreed to by an authorized representative of the aggregate producer.

Producer

Signed:

Signed:

Contractor

FIGURE A2: Mix design of 35.5% RAP.

Form 955r ver. 8.10

Iowa Department of Transportation Highway Division-Office of Materials

County :	Johnson		Project No.: STP-006-6(74)-2	2C-52		Date:	09/08/13	
Project Location:	In Iowa Ci	ty from 50	0' N of S Jct IA 1 to Lakeside Dr		Mix Desi	gn No.:	ABC13-	6043
Contract Mix Ton	nage:	300	Course: Surface (Tra	vel Lane)	Mix Size	(in.):	1/2	
Contractor:	L.L. Pelli	ng	Mix Type: HMA	(10M ESA	L), Surface	, 1/2, FR	ICL-3	
Material	Ident #	% in Mix	Producer & Location	Type (A or B)	Friction Type	Beds	Gsb	%Abs
Sand	A52508	11.0%	Williams/S&G Materials Inc	A	4		2.634	0.47
TAT4 M. Sand	A52006	14.0%	Klein/River Products Co	A	4	2-10	2.649	0.84
3/8"chips	A58002	12.0%	Columbus Junction/River Products Co	A	4	16-19	2.583	3.23
3/4" A	A52006	11.0%	Klein/River Products Co	Α	4	2-10	2.652	0.86
3/8" Slag	A70008	14.0%	Montpelier/Blackheart Slag	Α	2		3.709	1.20
RAP	Surface mi	38.0%	ABC13-0119 (3.38 % AC)	A	2	0	2.662	1.30
Type and Source of	Asphalt Bin	der	64-28 Bituminous Matr	1 & Supply ((ama IA)		1	

Individual Aggregates Sieve Analysis - % Passing (Target) 3/4" 1/2" 3/8" #4 #8 #16 #30 #50 #100 #200 Material 1 Sand 100 100 100 100 95 90 79 53 16 2 1 TAT4 M. Sand 100 100 100 100 98 76 43 20 8.3 2.8 2.5 2.7 2.5 2.3 50 4 2.6 100 100 100 95 15 3/8"chips 2 2 2.5 100 100 55 19 4 3 2.5 3/4" A 3 3/8" Slag 100 100 100 100 31 1.8 1.6 1.5 1.5 1.4 RAP 100 100 93 80 51 36 27 20 14 10 8.8

Preliminary Job Mix Formula Target Gradation

Upper Tolerance	100	100	99	90	61	42		21			6
Comb Grading	100	100	92	83	54	37	26.0	17.0	8.0	5.1	4.4
Lower Tolerance	100	100	85	76	47	32		13			2.4
S.A.sq. m/kg	Total	4.46		+0.41	0.22	0.30	0.43	0.49	0.55	0.62	1.44

Production Limits for Aggregates Approved by the Contractor & Producer.

Sieve	11.0%	ofmix	14.0%	ofmix	12.0%	ofmix	11.0%	ofmix	14.0%	ofmix	38.0%	ofmix
Size	Sa	nd	TAT4 I	M. Sand	3/8"	chips	3/4	" A	3/8"	Slag	R	AP
in.	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4"	100.0	100.0	100.0	100.0	100.0	100.0	98.0	100.0	100.0	100.0	98.0	100.0
1/2"	100.0	100.0	100.0	100.0	98.0	100.0	48.0	62.0	100.0	100.0	86.0	100.0
3/8"	98.0	100.0	98.0	100.0	88.0	100.0	12.0	26.0	98.0	100.0	73.0	87.0
#4	88.0	100.0	91.0	100.0	43.0	57.0	0.0	11.0	24.0	38.0	44.0	58.0
#8	85.0	95.0	71.0	81.0	10.0	20.0	0.0	8.0	0.0	6.8	31.0	41.0
#30	49.0	57.0	16.0	24.0	0.0	6.7	0.0	6.5	0.0	5.5	16.0	24.0
#200	0.0	3.0	0.5	4.5	0.3	4.3	0.0	4.0	0.0	3.0	6.8	10.8

Signed:

Comments: This is a revised report which includes field changes to the aggregate proportions

Copies to:

The above target gradations and production limits have been discussed with and agreed to by an authorized representative of the aggregate producer.

Signed:

Producer

Contractor

FIGURE A3: Mix design of 39.2% RAP.

APPENDIX B: PLANT REPORTS

99/13 1 1 1 Ame) 99/13 1 1 Lab Voids Targeto: 1 Lab Voids Targeto: 30 Design Gyrations: 36	F	ff. G _{mb} % of P _a (%) Thickness (in.)	3.2 2.430 94.7 5.3 1.63	6.7 2.488 97.0 3.0 1.38	7.2 2.448 95.4 4.6 1.38	3.8 2.447 95.4 4.6 1.75	7.8 2.435 94.9 5.1 1.75					Thickness Of	2.446	Ava. % of Gmm: 95.333	Ava. % Field Voids: 4.67		1.27 → PWL (lower) 90.3		Divit (unuar)	4.31 > 100.0	1000 - 003	-			Voids Price Adjustment = \$0.00			0 5:00 7:00 Spec Comply?		260-330 °F Yes	5 295 245-330 °F Yes	Bain Out De-trart after mandatory charlown	the day, identify them on previous day's report):	3 Initial % New % Agg Initia New %						and approved aggregate as	ed in compliance with the		
L w Placement: Surface [Travel L Mix Type: 10M Surface 1/2 L-3 toties Bid fem: 2302-005353 10M Surf 1/2/	COMPACTED MA	W1 W2 in H20 W3 Wet Di Dry (g) (g) (g) Di	712.4 420.0 713.2 29	613.9 367.4 614.1 24	8 654.0 387.0 654.2 26 950.0 400.0 650.2 26	s 841.4 498.3 842.1 34	846.9 499.6 847.4 34					Surface (Travel ane)		09/08/13	09/08/13 Mike Bloom		65 x 2.565) - 2.446 =	0.023	6 (0.915 x 2.565)	0.023	1000 T		00 ton plan quantity.		Field	a second s	TEMPERATURE, *F	9:00 11:00 1:00 3;00	76	300	293 296	Break Drue	e Information (when changes are made to start t	Old Target New Target Tons Agg						alt mixture contains certified asphalt binder	in the approved mix design and was produc		
NG DAILY PLANT REPORT Pelling Act mison Act		5) Core Station Reference	1 268+95 6.3 SW Pas	2 268+72 8.7 SW Pag	3 265+07 6.4 SW Pas	5 259+52 54 SWP Pas	6 256+10 3.1 SIM Pas	2	•			Course Placer	Control of the Property	Date Placed:	Test Date/By:		Q.I. (lower) = (0.9)		244	O.I. (upper) =	DMI Actelh =		Article 2303.03,E Applies for 3					15 Time 7:00	Air Temp 83	Ibi Binder Temp 300	0 Mat Temp	12	D Mix Chang			Width (T	2		Comments	The asph	Cert. No. EC593 specified	Contractor	
Representation of the second s	COMPACTED JOINT	Core Lane Gre (%) (Gmm=2.56	1	+	÷ •	\$	2-	2.	3	ó		Average Pa (%)		USE D.O.T. RESULTS	(Enter an 'X')			TEST STRIP			FILM THICKNESS (FT) [8.0-15.0]	FT, µm 9.7	Price Adjustment \$0.00	Octoor And			QUANTITY FOR PAYMENT	Mix Unit Price (\$/ton) \$48.5	Binder Unit Price (\$/ton) \$686.2	Tone to Other Bid Item/s)	Tons of Binder 13.9	Tons of Waste 14.6	Tons of Binder to Date 13.90	Tons of Mix to Date 290.06	PLACEMENT RECORD	OII 10 Station Lane	200742 OUTVUI 000				the second se	Dist Materials Proj Environer	
80						Ī					- D- 60	65 27 Avg Pa (%)		Tota stu	District	100	100	93	3 83	-	40	-	2	70	110	6.6	5.2	1.4	Yes	107.6		2 30.2/9.3				LIGHT STATE	-];	Certified Ter	Contraction of Contra	1
R											0.000	2 497 2 5		(Dui	Avg	100.0	100.0	93.0	29.0	0	39.0	-2.0	27.0	19.0	8.8	5.0	3.9	0.1	Yes	100.0	0.0	31.0/05			San Comb	Spec Lompi	4.40-5.00 Yes	s100% Yes		≤ 30% Yes	64-28 Yes	Phe (%) - 4 24	that an a
<u>3/6/2013</u> 3719-006-6(74)-2C-52 0: 52-0015-101 5: ABC13-6041	UNCOMPACTED MIXTURI	a 🔆		Σ								ties) Applies for 300 ton plan		GRADATION (%Pass	Su9-8	100.0	100.0	3) 93.0	94.0	0	0 39.0	-2.0	21.0	19.0	8.8	5.0	8) 3.9	0.1	Yes	10.02		31.0/09.2			BINDER	· 3 70 3 82	4.80	29.00 30.03%		20.07% 20.36%	04-28	Geb: 2734	
Active Project N Active Project N Mix Design N		Hot Box I.D. Su9-85 (Theoretical (4.80%	Date Sampled 9/8/13	Time 7:31 Ph	Station	Sample (Tons) 116.00	Gmb 2.497	Gmb (DOT) (h) 2.509	Gmm (DOT) (In) 2:5/0	P _a (%) 2.7	P. (%) (DOT) 2.4	Article 2303.03,E (Small Quantity quantity			Sieve Specs	1 in. 100	3/4 in. 100	1/2 in. 86-100(9. 3/8 in 7e 02/96	*#4 52-66(59	* Dev ± 7.0	*#8 36-46(41	-Dev ± 5.0	#10	#30 14-22(18	#50 - Dev # # *.0	#100	#200 1.8-5.8(3.8	*Dev ± 2.0	Gradation Compliance?	% +4 Tune 4 R0	% +4 Type 3 45	(+4/-4) Type 2 (25/0)				94. Addad Bindar	% Total Binder	% RAP	% RAS	% Binder Replacement	PG Grade	Gb: 1.01826	An on the second se

FIGURE B1: Plant Report for 30.0% RAP.

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	Develop Surface Surface <t< th=""><th>ao number, ABC-15-0119 (3.38 % AC) Active Bid Item: 2303-0053503 10M Surf 1/2in L-3 (HMA) Design Gyrations: 96</th><th>COMPACTED JOINT COMPACTED MAT</th><th>Lane G_{ine} (Gimm=2.573) Core Station Reference DY (a) W1 W2 in H20 W3 Wet Diff. G_{ine} % of P_a (%) Thickness (in)</th><th>1 252+63 lo4 SWPass 728 2 429 1 728 4 200 3 2 424 5 6 1 50</th><th>2 247+19 328WPass 774,4 4571 775,0 317,9 2436 94,5 5,5 1,50</th><th>3 245+53 15 SWPares 815.0 473.5 815.7 342.2 2.382 92.4 7.6 1.63</th><th>4 242+27 1.05W Pairs 820.4 483.0 821.2 338.2 2.426 94.1 5.9 1.63</th><th>5 2339-36 628 WP asso 827/1 489.1 827.5 338.4 2.44 94.8 5.2 163</th><th>01UU 4/4.3 01UD 330.7 2.413 01UD 300.7 1.0.0 0.0 1.00</th><th></th><th></th><th></th><th></th><th>Course Placed: Suiface (Travel Lane) Thickness OI: 4.67</th><th>Interded Lift Thickness 150 Avv Mat Davide 2422 600</th><th>USE D.O.T. RESULTS Date Placed: 09/08/13 Aug. % of Game: <u>93.967</u></th><th>(Eriter an 'X') Test Date/By: 09/08/13 Milke Bloom Avg. 's Field Voids: 6.03</th><th></th><th>TEST STDID <math>0.1. (lower) = (10.302 \times 2.376) - 2.422 = 2.99 $\rightarrow PWL (lower) = 100.0$</math></th><th></th><th>Q1. (upper) = 2.422 - (0.915 × 2.578) = 2.87 → PwL (upper) 100.0</th><th>0.022</th><th>TI TI T</th><th>e Adjustment \$0.00 Arricle 2303.03,E Applies for 300 tan plan quantity.</th><th></th><th>IX Unapproved (See IM 510A) Field Voids Price Adlustment = \$0 DD</th><th>VIMY % 1759</th><th>DUANTITY FOR PAYMENT</th><th>Mit Price (\$ten) \$48.55 Time 7.00 9.00 11:00 1:00 5:00 7:00 Spec Compty</th><th>Unit Price (\$kon) \$686.20 Air Temp 76 75 D</th><th>of Mix on Road 312.52 Binder Temp 300 300 500 260-330 °F Yes Other Bid Illowici</th><th>Trans d Binder 14.04 Mai Temp 000 002 102 100 245-300 100 1245-330 17 100 1245-300 17 100 1245-300 17 100 1245-300 17 100 1245-300 17 100 1245-300 17 100 17</th><th>All Character and All Character (in the character (in the character of the character of the character of character of th</th><th></th><th>orum kortuster joitz. Z. wu rangen neew langen turis 7499 intuatine neew zo 749 intuatine neew zo 749 intuatine neew zo 251. Zettektin Factoria</th><th>T Shattion Turketion (Middle All and Middle All and M</th><th>10 determine the second s</th><th></th><th></th><th>Comments: The sechalt mixture contains contains contrained account functor and concerned economics on</th><th>Tartor Maxfield Cert. No. EC593 specified in the approved mix design and was produced in compliance with the</th><th>Dave McDowell Cert, No EC898 provisions of Article 2033,05, E.</th><th>Materials</th></t<>	ao number, ABC-15-0119 (3.38 % AC) Active Bid Item: 2303-0053503 10M Surf 1/2in L-3 (HMA) Design Gyrations: 96	COMPACTED JOINT COMPACTED MAT	Lane G _{ine} (Gimm=2.573) Core Station Reference DY (a) W1 W2 in H20 W3 Wet Diff. G _{ine} % of P _a (%) Thickness (in)	1 252+63 lo4 SWPass 728 2 429 1 728 4 200 3 2 424 5 6 1 50	2 247+19 328WPass 774,4 4571 775,0 317,9 2436 94,5 5,5 1,50	3 245+53 15 SWPares 815.0 473.5 815.7 342.2 2.382 92.4 7.6 1.63	4 242+27 1.05W Pairs 820.4 483.0 821.2 338.2 2.426 94.1 5.9 1.63	5 2339-36 628 WP asso 827/1 489.1 827.5 338.4 2.44 94.8 5.2 163	01UU 4/4.3 01UD 330.7 2.413 01UD 300.7 1.0.0 0.0 1.00					Course Placed: Suiface (Travel Lane) Thickness OI: 4.67	Interded Lift Thickness 150 Avv Mat Davide 2422 600	USE D.O.T. RESULTS Date Placed: 09/08/13 Aug. % of Game: <u>93.967</u>	(Eriter an 'X') Test Date/By: 09/08/13 Milke Bloom Avg. 's Field Voids: 6.03		TEST STDID $0.1. (lower) = (10.302 \times 2.376) - 2.422 = 2.99 \rightarrow PWL (lower) = 100.0$		Q1. (upper) = 2.422 - (0.915 × 2.578) = 2.87 → PwL (upper) 100.0	0.022	TI T	e Adjustment \$0.00 Arricle 2303.03,E Applies for 300 tan plan quantity.		IX Unapproved (See IM 510A) Field Voids Price Adlustment = \$0 DD	VIMY % 1759	DUANTITY FOR PAYMENT	Mit Price (\$ten) \$48.55 Time 7.00 9.00 11:00 1:00 5:00 7:00 Spec Compty	Unit Price (\$kon) \$686.20 Air Temp 76 75 D	of Mix on Road 312.52 Binder Temp 300 300 500 260-330 °F Yes Other Bid Illowici	Trans d Binder 14.04 Mai Temp 000 002 102 100 245-300 100 1245-330 17 100 1245-300 17 100 1245-300 17 100 1245-300 17 100 1245-300 17 100 1245-300 17 100 17	All Character and All Character (in the character (in the character of the character of the character of character of th		orum kortuster joitz. Z. wu rangen neew langen turis 7499 intuatine neew zo 749 intuatine neew zo 749 intuatine neew zo 251. Zettektin Factoria	T Shattion Turketion (Middle All and Middle All and M	10 determine the second s			Comments: The sechalt mixture contains contains contrained account functor and concerned economics on	Tartor Maxfield Cert. No. EC593 specified in the approved mix design and was produced in compliance with the	Dave McDowell Cert, No EC898 provisions of Article 2033,05, E.	Materials
A () A	Z 9		r IM 511.	Core	÷	÷	÷	÷	~	2 4	2.	e .	ej ej	va Pa (%) 3-	2.8 A		Use DOT	District	100	07	68	62	3		29 Pric	20	3.0 Mi	7.2	5.7	1.5 Mix L	Yes Binder	1.45 Tons 1.22.2 Tons to		5.4/9.2 To	Tons		From Station	253+42				Certified Tech:	Certified Tech:	Distribution: Dist.
Je Le	17		on-validation pe							t				Avg G A	2.578			Avg	100.0	03.0	84.0	57.0	-2.0	-3.0	26.0	17.0	•	5.5	4.5	0.3	Yes	1.14	0.0	31.3/10.0 3		Γ	CompN?	- fortupo	Yes	Yes	Ves	Yes		3.94
			E Investigate nu											Avg Gat	2.507		ing)									,											Spec	N/A	4.20-4.80	\$100%	< 30%	64-28		Pbe (%):
	9/8/2013 5TP-006-6(74)2C-52 52-0015-101 52-0015-010	7400-61084	UNCOMPACTED MIXTUR.					-							upplies for Juu ton plan		GRADATION (%Pass	Su9-8b	0.001	93.0	84.0	57.0	-2.0	-3.0	26.0	17.0	•	5.5	4.5	0.3	Yes	100.0		31.3/10.0		/ BINDER	Target Actual	3,40 3.33	4.50 4.49	34.00 35.53%	25.85%	64-28		Gsb: 2.735
	Active Project No.: 5 Active Project No.: 5 Active Project No.: 5 Max Design Mo. 5			Hot Box I.D. Su9-8b (Theoretical (4.49%) %AC)	Date Sampled 9/8/13	Time 9:15 PM	Station	Side	G	Gmb (DOT) (In) 2.513	G _m 2.578	Gmm (DOT) (Out) 2.595	P. (%) (DOT) 3.2		Autos 2003.03,E (Small duamines) A quantity			Sieve Specs	1 m. 100 3/4 in 100	1/2 in. 87-100(94)	3/8 in. 79-93(86)	#4 52-66(59)	* Dev ± 7.0	•Dev ±5.0	116	#30 13-21(17)	* Dev ± 4.0	100	#200 2.2-6.2(4.2)	*Dev ± 2.0	Gradation Compliance?	%+4 Type 4 80	% +4 Type 3 45	(+4/-4) Type 2 (25/0)				% Added Binder	% Total Binder	% RAP	% RAS % Rinder Replacement	PG Grade		Gb: 1.01906

FIGURE B2: Plant Report for 35.5% RAP.

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PLANT REPORT Active Placement: Surface (Travel Lane) Mix Type: <u>10M Surface 1/2 L-3 (HMA)</u> Lab Vois Target: <u>4.0</u> Active Bet term: <u>2302-005303 101 Surf 7/2m-1.3 (HMA)</u> Lab Vois Target: <u>4.0</u>	COMPACTED MAT	Station CL W1 W2 in H20 W3 Wet Diff. Gee % of Pa (%) Thickness (in.)		234+65 30 SW Pass 819.5 479.5 820.0 340.5 2.407 92.3 7.7 1.63 224+65 45 SW Pass 87.9 546.5 868 3 351 8 2.467 04.6 5.4 175	229433 80 SWP Pees 814 9 487 5 815 1 327 6 2 487 95 4 7 1 50	216+40 78 SW Pass 715.3 422.9 715.9 293.0 2.441 93.6 6.4 1.50	213+891.0 SWPass 701.3 417.2 701.9 284.7 2.463 94.4 5.6 1.25	203+39 7.2 SIW Pass 650.4 389.9 650.8 260.9 2.493 95.6 4.4 1.25						Course Placed: Surface (Iravel Lane) Thickness QI: 0.96	ended Lift Thickness: 1.50 Avg. Mat Density. 2.400	Tast Distortion US/UG/13 Million Discom Auro of Firld Variation 1570		(0.965 x 2.609) — 2.460 — 4.50 PWI (lower)		2 460 - 10 04E - 2 6001	$pet) = \frac{2.450 - (0.313 \times 2.003)}{0.032} = 2.27 \rightarrow PWL (upper) = 99.9$		100.0 = 38.0 + 39.9 - 100.0 = 97.9	03.03,E Applies for 300 ton plan quantity.		Field Voids Price Adjustment = \$0.00		TEMPERATURE, "F	ne 7:00 9:00 11:00 1:00 3:00 5:00 7:00 Spec Compt/	emp 83 76 75	Temp 300 300 300 300 F Yes	Temp 320 309 322 245-330 F Yes		☐ Break Dow ☐ Rain Out ☐ Re-start after mendatory shutdown <u>Mix Change Information</u> (when changes are made to start the day, identify them on previous day's report):	Old Target New Target Tons Agg Initial % New % Agg Initia New %						Comments: The asohalt mixture contains certified asohalt hinder and annound annound as	2593 specified in the approved mix design and was produced in compliance with the	2898 provisions of Article 2303.03, E.	
ENALLAN AND AND AND AND AND AND AND AND AND A	COMPACTED JOINT	Core Lane Gmb //Gmm=2 600) Core		+ +			2-	2-	× ×		3-	~	3- Automote Da /ML	Average Ta (%)		(Enter an 'Y')			TEST STRIP	(Enter an "X")	O.I.	FILM THICKNESS (FT) [8.0-15.0]	FT, µm 8.2	Price Adjustment \$0.00 Article			0.11 0/ 'WWA	QUANTITY FOR PAYMENT	Mix Unit Price (Ston) : \$48.55	Binder Unit Price (\$/ton) \$686.20 Ai	Tons of Mix on Road 317.54 Binc	Tons to Other Bid Item(s) 13 02 Pla	Tons of Waste	Tons of Binder to Date 13.92	Tons of Mix to Date 317.54	PLACEMENT RECORD	ion To Station Lane Width (ft)	226+27 SB/WB Pass Lr 12	206+60 SBWB Pass Lr 12			ch: Tavlor Maxfield Cert. No.	ch: Dave McDowell Cert. No.	Dist Materials Proj. Engineer Contractor
													19 Gmm Avg Pa (%)	C.2 600.2	<	Ava District	00.0 100	00.0 100	91.0 92	79.0 83	2.0 3	35.0 39	2.0 2	25.0 28	7.0 21	120.4	5.3 :7.5	4.4 6.0	0 1.6	res Yes	20 1.63	0.01 113.0	1/12.6 35.9/11.5				mply? From Statt	235+54	es 217+60	8	(es	es Certified Tec	Certified Ter	67 Distribution:
121 121	ure												Avg Gmb A	A+C-7	teeinal	fRuieon																	32.			-	Spec Co	A/A	% \$100-4.60	00011	% s 30%	64-28		Pbe (%): 3
3/8/2013 STP-006-6(74)2C- 52-0015-101 ABC13-6043	JNCOMPACTED MIXTL												Applies for 300 ton plan		CDADATION / 20	Su9-8c	100.0	100.0	91.0	52.0 52.0	-2.0	35.0	-2.0	0.62	17.0	00	5.3	4.4	0	Yes	1.20	100.0	32.1/12.6			BINDER	Target Actual	3.10 3.11	38.00 39.219	14:00	28.96% 29.29%	64-28		Gsb: 2.754
Active Project No.	ſ	Hot Box I.D. Su9-8c Theoretical (4 3.8%)	ate Samulari 0/8/13	me campred 3/0/13	tation	de	ample (Tons) 259.00	a 2.549	mb (pot) (In) 2.551	mm (DOT) (In) 2.614	(%) 2.3	(%) (DOT) 2.4	icle 2303.03,E (Small Quantities) A antity			Sieve Specs	n. 100	l in. 100	c in. 85-99(92)	4 47-61(54)	* Dev ± 7.0	32-42(37)	*Dev ± 5.0		0 13-21(17)	. Dev III.		00 2.4-6.4(4.4)	*Dev ±2.0	Gradation Compliance?	DBR 0.6-1.4	+4 Type 3 45	4/-4) Type 2 (25/0)					% Added Binder	% Total Binder % RAP	% RAS	% Binder Replacement	PG Grade		Gb: 1.01956

FIGURE B3: Plant Report for 39.2% RAP.

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