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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

Graduate College
The University of Iowa
Iowa City, Iowa

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

Thesis Committee: Hosin “David’ Lee, Thesis Supervisor

Wilfrid Nixon

Paul Hanley

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 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.

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

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. ≤ 1M ESAL	- 10% Interm. ≤ 1M ESAL
-No limit in other layers	-20% Base for all ESAL	- 10% Base for all ESAL

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.

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

Size of RAP	Recovered Aggregate Composition After Ignition Oven Burn-Off – (% Retained)											% Asphalt Content	% of Stockpile	% of Dust Content
	¾”	½”	3/8”	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	Pan			
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**
¾”	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**
½”	---	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%**

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:

$$\begin{aligned}&Percent\ Binder\ Replacement\\ &\quad = \frac{(\%\ of\ Binder\ Content\ in\ RAP \times \%\ of\ RAP\ in\ Mix)}{Total\ \%\ of\ Binder\ in\ the\ Mix} \times 100\end{aligned}$$

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.

Table 3: Volumetric Mix Design Criteria

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 4: Mix Design Summary

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

*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.

Table 5: Percent RAP by Weight and by Binder Replacement

	29% RAP by weight		34% RAP by weight		38% RAP by 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%

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.

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

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 (P_{be})	4.24	3.94	3.67
Mix Design Criteria			
VMA (%)>14	13	12.5	11.5
70<VFA (%)<80	79.6	78.0	80.0
Dust Content<10	3.8	4.2	4.4
8<Film Thick<13	9.7	8.6	8.2
0.6<DB Ratio<1.4	0.92	1.14	1.2

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.

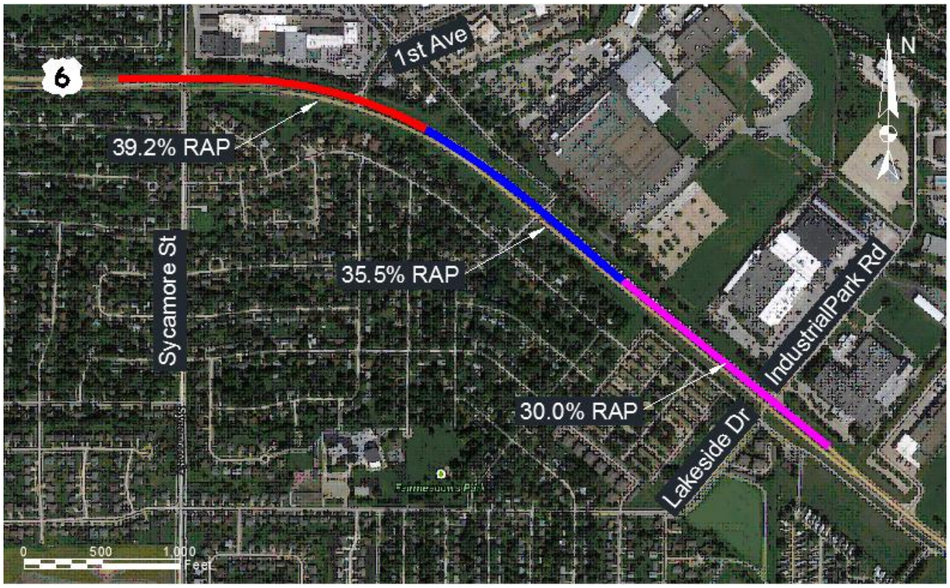
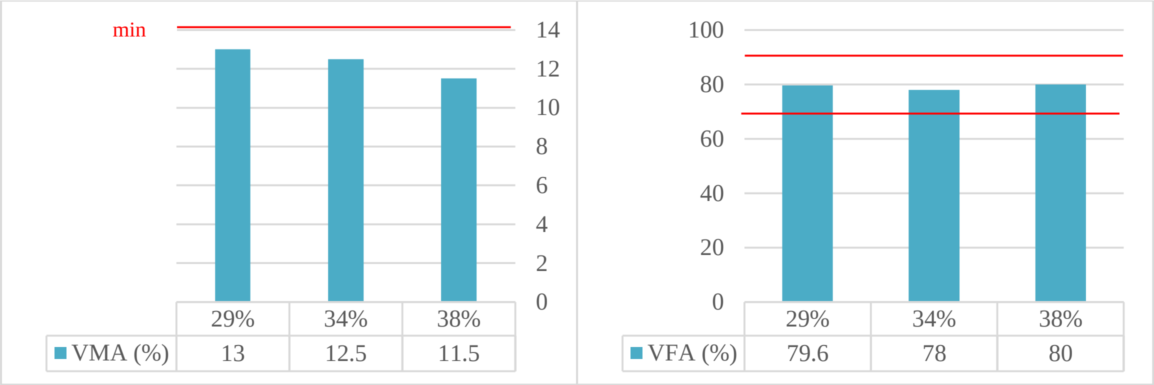
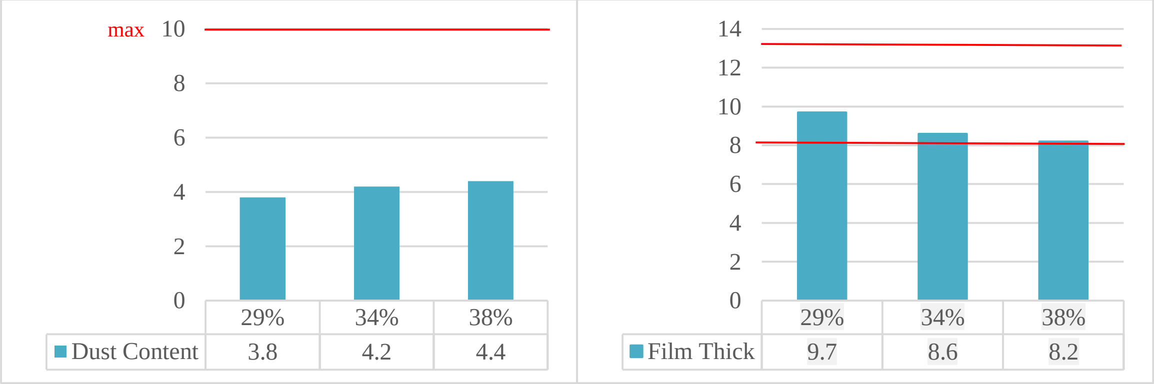


FIGURE 1: Layout of test sections.

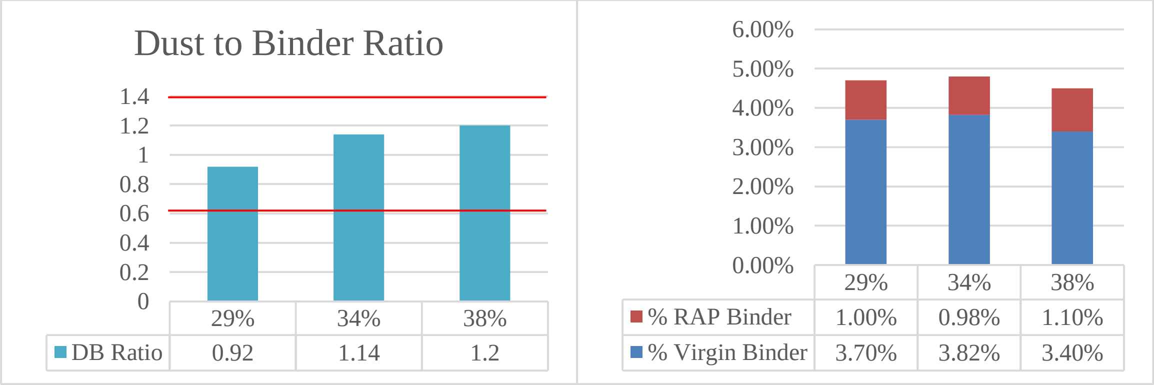
Volumetric mix design results are plotted in Figure 2. The fractionation method was effective in reducing the amount of fine aggregates from the original stockpile and thereby improving volumetric properties. These volumetric properties of mixtures were influenced by the optimum asphalt content of each 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) (b) Voids Filled with Asphalt (VFA)



(c) Dust Content (d) Film Thickness



(e) Dust to Binder Ratio (f) Optimum Asphalt Cement Content

FIGURE 2: Volumetric mix design criteria.

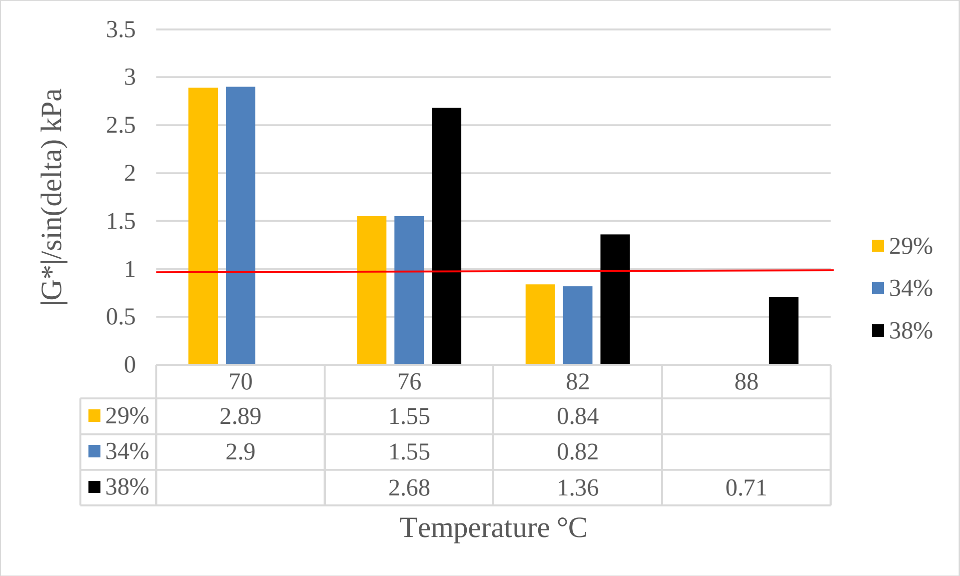
EVALUATION OF HIGH RECYCLED ASPHALT PAVEMENT MIX DESIGNS

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 ºC, 76 ºC, and 82 ºC respectively. These high temperatures are two or three levels higher than the high temperature of 64 ºC 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.



	70	76	82	88
🟨 29%	2.89	1.55	0.84	
🟦 34%	2.9	1.55	0.82	
■ 38%		2.68	1.36	0.71

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 ºC, -6 ºC, and -12 ºC respectively. These temperatures are one or two levels higher than the low test temperature of -18 ºC 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.

Table 7: Bending Beam Rheometer Data

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		

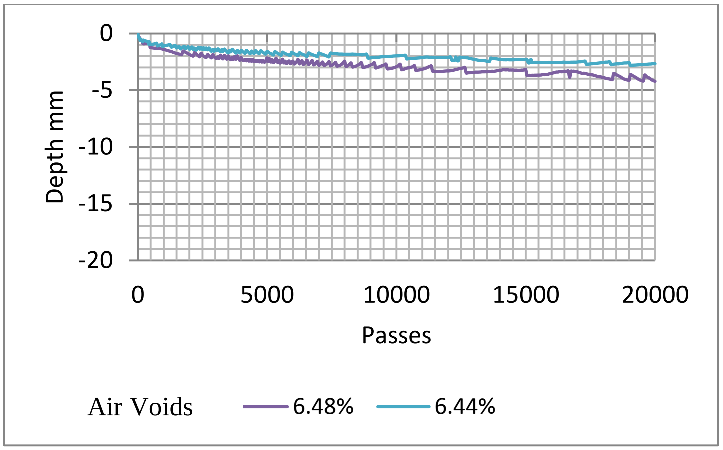
Based on both DSR and BBR test results, the PG grade of extracted binders from the field mixtures with 30.0%, 35.5% and 39.2% FRAP can be classified as PG 76-22, PG 76-16, and PG 82-22 respectively. It can be concluded that the virgin binder of PG 64-28 used to build the test sections high temperature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

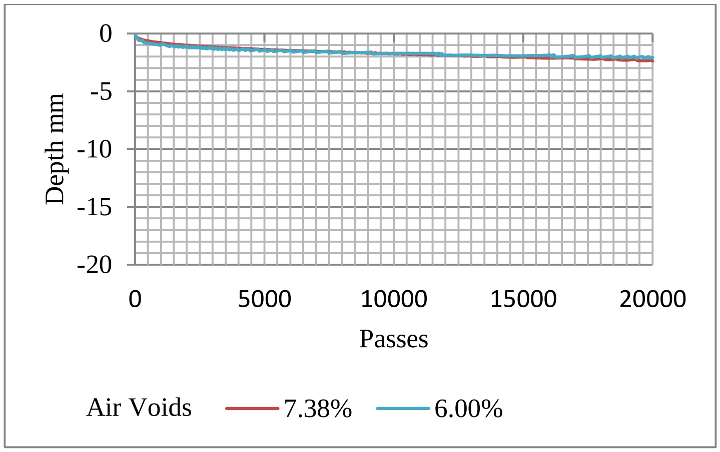
In order to evaluate the moisture susceptibility of field mixtures with varying FRAP amounts, the Hamburg Wheel Tracking Test (HWTT) was performed following the AASHTO T324 procedure and multiple pictures of the Hamburg Wheel Tracking Device can be seen in Figure 4. HWTT applies a constant load of 685 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.

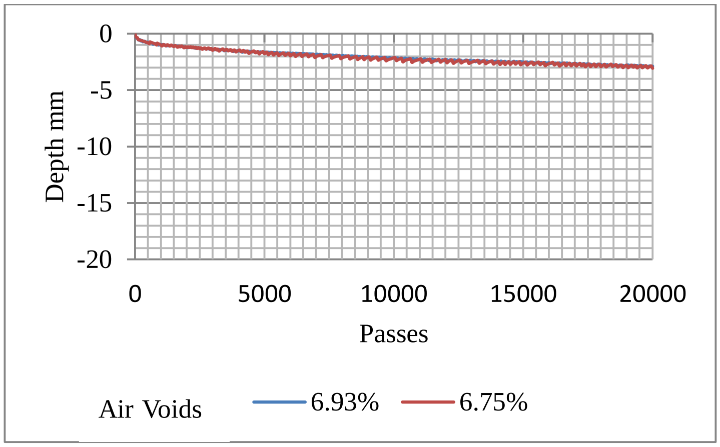
Figure 5 shows the HWTT results for field mixtures with 30.0%, 35.5%, and 39.2% FRAP by weight. The target air voids for each sample was 6% which can be considered as a typical field density. All specimens exhibited excellent performance with little rutting resulting in a lack of a stripping inflection 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.



(a) 30.0% FRAP



(b) 35.5% FRAP



(c) 39.2% FRAP

FIGURE 5: Hamburg Wheel Tracking Test results of high-FRAP field mixtures.

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. 30.0% FRAP Field Core 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

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.

(a) Low **(b) Medium** **(c) High**

FIGURE 6: Examples of low, medium, and high severity cracking.

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.

Table 9: Transverse Cracking Developed in Three Test Sections

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

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.

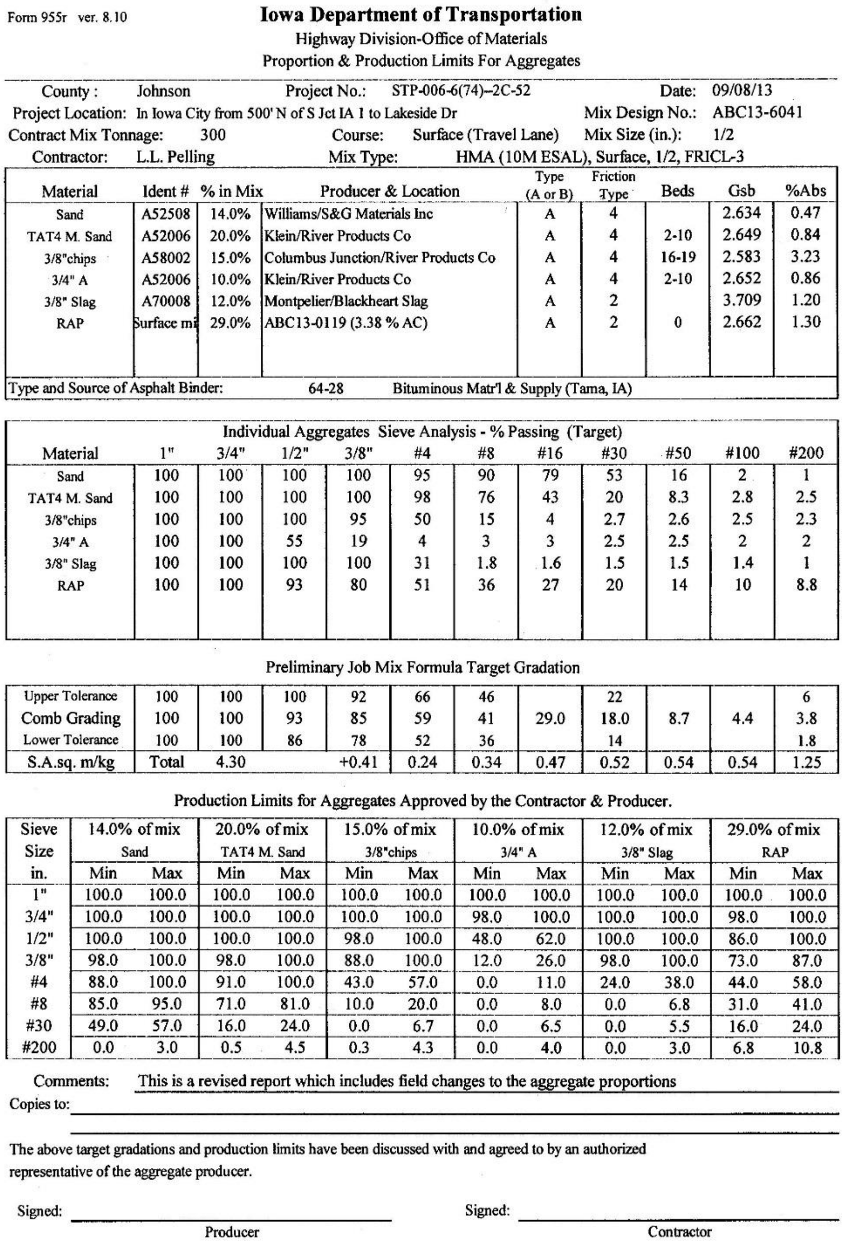
Three test sections with actual amounts of 30.0%, 35.5% and 39.2% FRAP were constructed on Highway 6 in Iowa City and the average field densities measured from the cores were 95.3%, 94.0%, and 94.3%, respectively, which met density requirement of 94% ± 2.0%. Superpave binder tests were performed to determine 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

Proportion & Production Limits For Aggregates

County : Johnson
Project No.: STP-006-6(74)--2C-52
Date: 09/08/13
Project Location: In Iowa City from 500' N of S Jct IA 1 to Lakeside Dr
Mix Design No.: ABC13-6041
Contract Mix Tonnage: 300
Course: Surface (Travel Lane)
Mix Size (in.): 1/2
Contractor: L.L. Pelling
Mix Type: HMA (10M ESAL), Surface, 1/2, FRICL-3

Material	Ident #	% in Mix	Producer & Location	Type (A or B)	Friction Type	Beds	Gsb	%Abs
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

Type and Source of Asphalt Binder: 64-28 Bituminous Matr'l & Supply (Tama, IA)

Individual Aggregates Sieve Analysis - % Passing (Target)

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		+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	14.0% of mix		20.0% of mix		15.0% of mix		10.0% of mix		12.0% of mix		29.0% of mix	
Size	Sand		TAT4 M. Sand		3/8"chips		3/4" A		3/8" Slag		RAP	
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

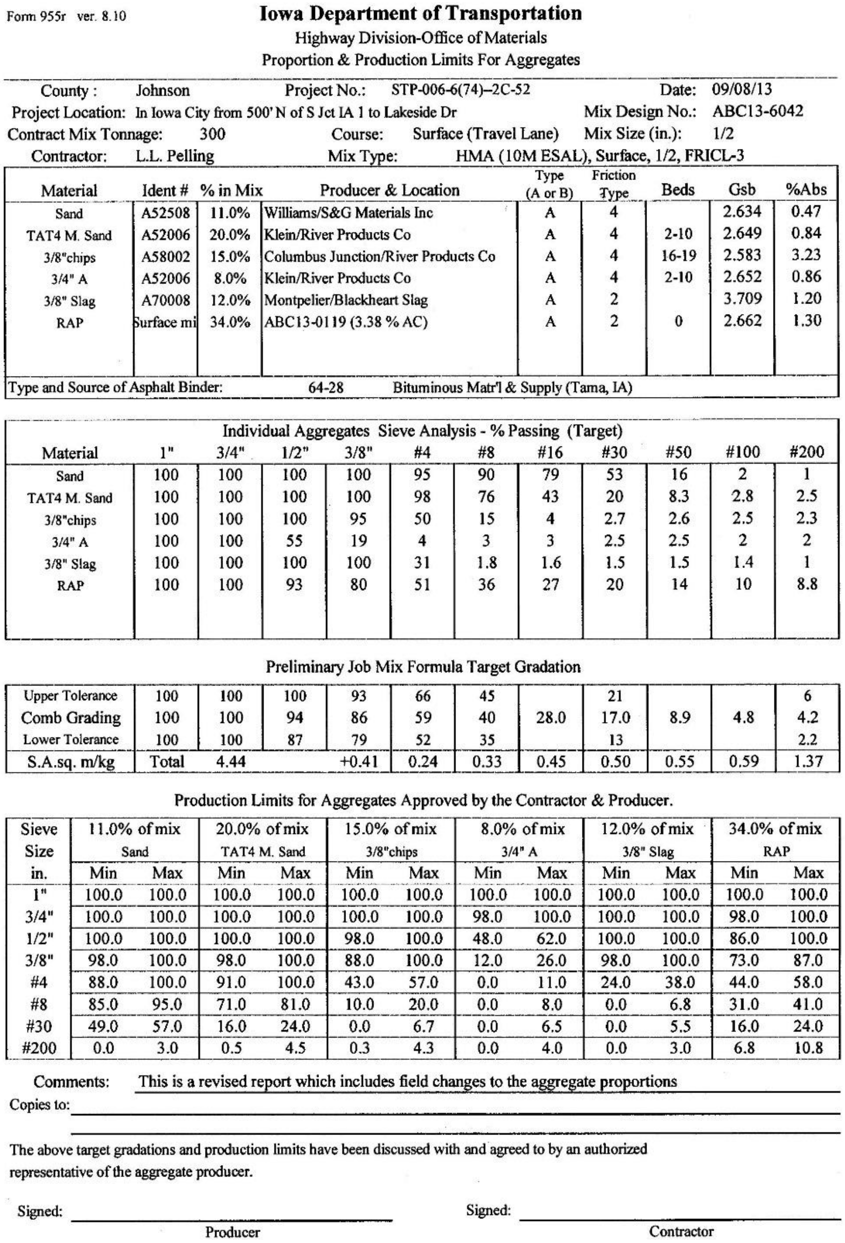
Comments: This is a revised report which includes field changes to the aggregate proportions

Copies to:

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

Signed: Producer
Signed: Contractor

FIGURE A1: Mix design of 30.0% RAP.



Form 955r ver. 8.10

Iowa Department of Transportation

Highway Division-Office of Materials

Proportion & Production Limits For Aggregates

County : Johnson
Project No.: STP-006-6(74)–2C-52
Date: 09/08/13
Project Location: In Iowa City from 500' N of S Jct IA 1 to Lakeside Dr
Mix Design No.: ABC13-6042
Contract Mix Tonnage: 300
Course: Surface (Travel Lane)
Mix Size (in.): 1/2
Contractor: L.L. Pelling
Mix Type: HMA (10M ESAL), Surface, 1/2, FRICL-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 Binder: 64-28 Bituminous Matr'l & Supply (Tama, IA)

Individual Aggregates Sieve Analysis - % Passing (Target)

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% of mix Sand		20.0% of mix TAT4 M. Sand		15.0% of mix 3/8"chips		8.0% of mix 3/4" A		12.0% of mix 3/8" Slag		34.0% of mix RAP	
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

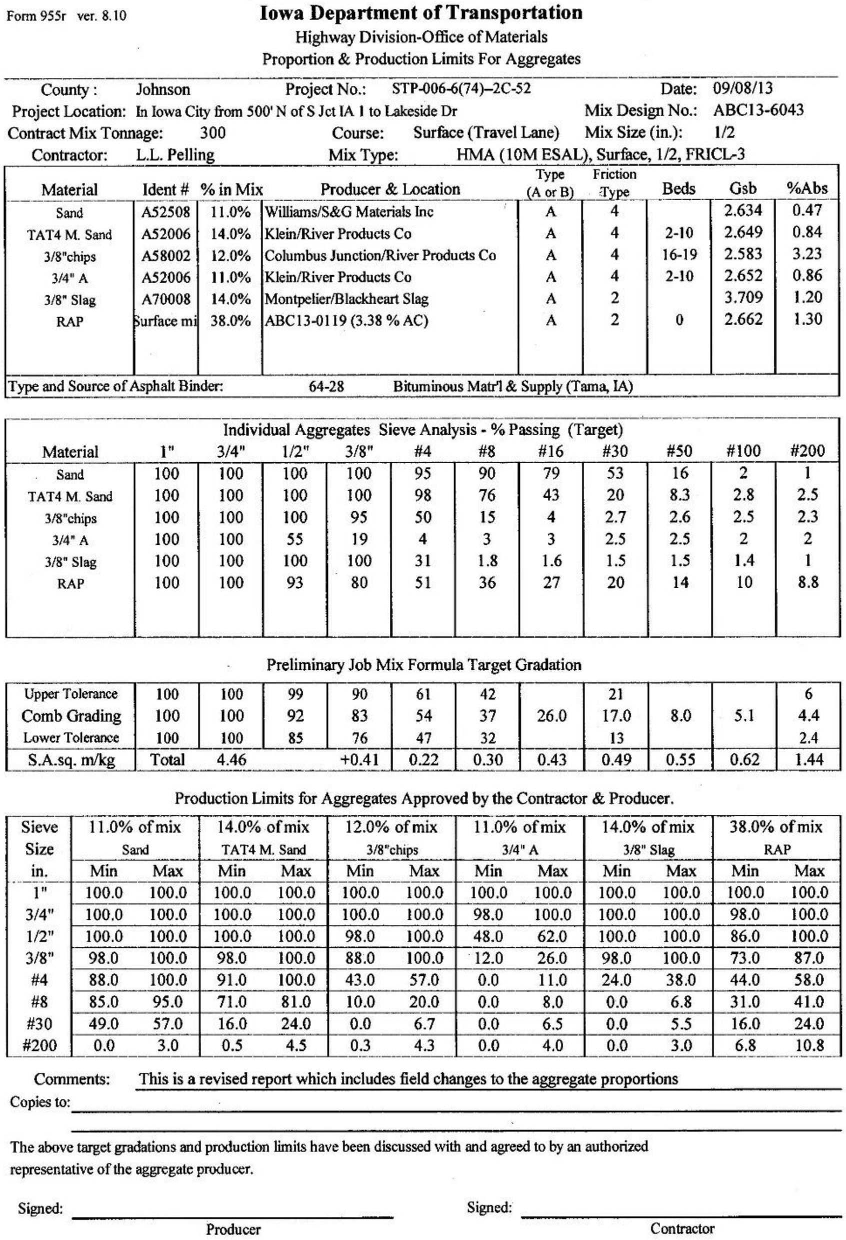
Copies to:

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

Signed: Producer

Signed: Contractor

FIGURE A2: Mix design of 35.5% RAP.



Form 955r ver. 8.10

Iowa Department of Transportation

Highway Division-Office of Materials

Proportion & Production Limits For Aggregates

County : Johnson
Project No.: STP-006-6(74)–2C-52
Date: 09/08/13
Project Location: In Iowa City from 500' N of S Jct IA 1 to Lakeside Dr
Mix Design No.: ABC13-6043
Contract Mix Tonnage: 300
Course: Surface (Travel Lane)
Mix Size (in.): 1/2
Contractor: L.L. Pelling
Mix Type: HMA (10M ESAL), Surface, 1/2, FRICL-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	A	4	2-10	2.652	0.86
3/8" Slag	A70008	14.0%	Montpelier/Blackheart Slag	A	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 Binder: 64-28 Bituminous Matr'l & Supply (Tama, IA)

Individual Aggregates Sieve Analysis - % Passing (Target)

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	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 Size in.	11.0% of mix Sand		14.0% of mix TAT4 M. Sand		12.0% of mix 3/8"chips		11.0% of mix 3/4" A		14.0% of mix 3/8" Slag		38.0% of mix RAP	
	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

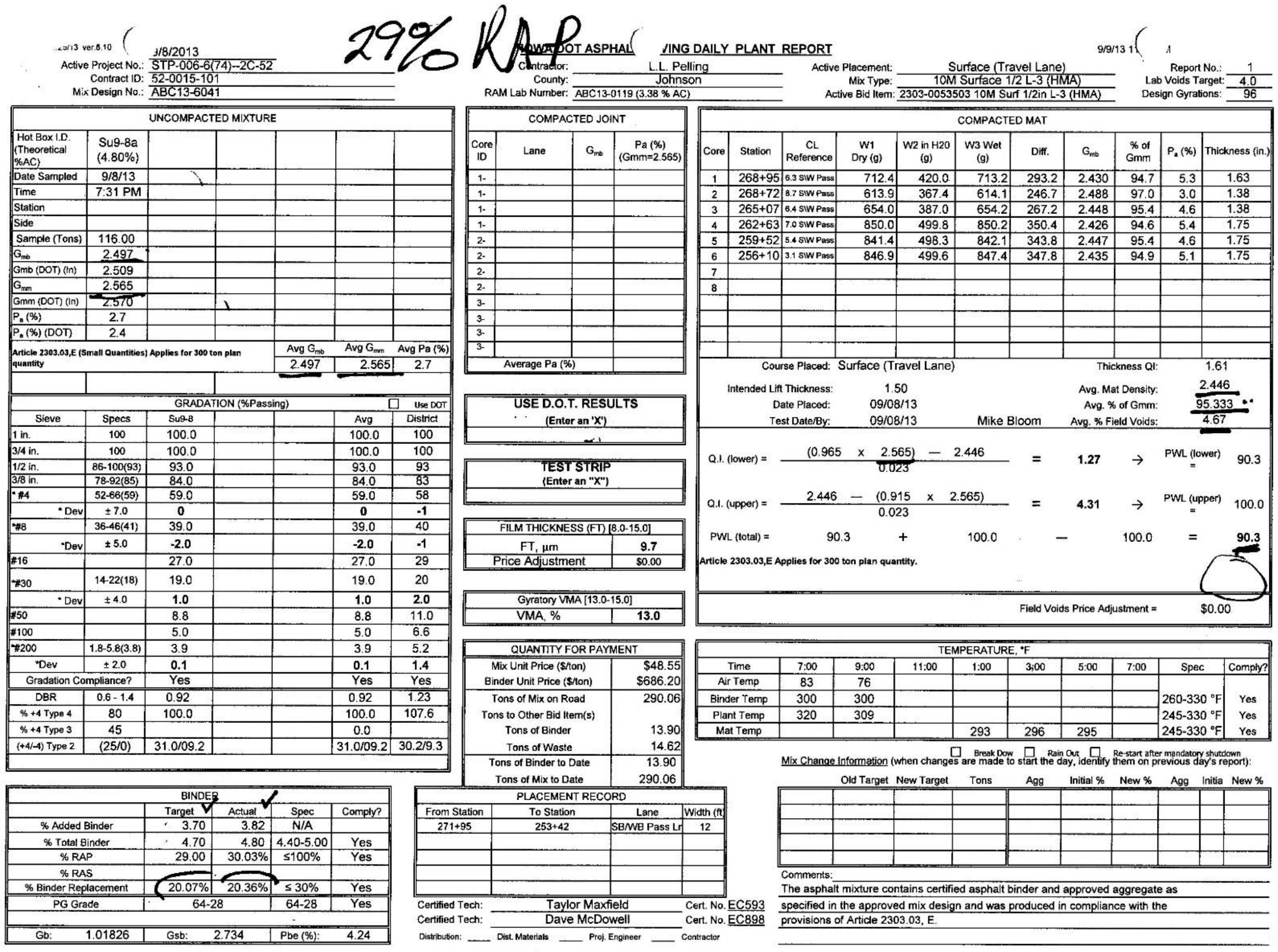
Copies to:

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

Signed: ____________________ Producer
Signed: ____________________ Contractor

FIGURE A3: Mix design of 39.2% RAP.

APPENDIX B: PLANT REPORTS



..25/13 ver.6.10 /8/2013

Active Project No.: STP-006-6(74)--2C-52
Contract ID: 52-0015-101
Mix Design No.: ABC13-6041

29% RAP

IOWA DOT ASPHAL VING DAILY PLANT REPORT

Contractor: L.L. Pelling
County: Johnson
RAM Lab Number: ABC13-0119 (3.38 % AC)

Active Placement: Surface (Travel Lane)
Mix Type: 10M Surface 1/2 L-3 (HMA)
Active Bid Item: 2303-0053503 10M Surf 1/2in L-3 (HMA)

9/9/13 1

Report No.: 1
Lab Voids Target: 4.0
Design Gyrations: 96

UNCOMPACTED MIXTURE

Hot Box I.D. (Theoretical %AC)	Su9-8a (4.80%)					
Date Sampled	9/8/13					
Time	7:31 PM					
Station						
Side						
Sample (Tons)	116.00					
G_{mb}	2.497					
Gmb (DOT) (In)	2.509					
G_{mm}	2.565					
Gmm (DOT) (In)	2.570					
P_a (%)	2.7					
P_a (%) (DOT)	2.4					

Article 2303.03,E (Small Quantities) Applies for 300 ton plan quantity

Avg G_{mb}	Avg G_{mm}	Avg Pa (%)
2.497	2.565	2.7

GRADATION (%Passing) ☐ Use DOT

Sieve	Specs	Su9-8			Avg	District
1 in.	100	100.0			100.0	100
3/4 in.	100	100.0			100.0	100
1/2 in.	86-100(93)	93.0			93.0	93
3/8 in.	78-92(85)	84.0			84.0	83
* #4	52-66(59)	59.0			59.0	58
* Dev	± 7.0	**0**			**0**	**-1**
*#8	36-46(41)	39.0			39.0	40
*Dev	± 5.0	**-2.0**			**-2.0**	**-1**
#16		27.0			27.0	29
*#30	14-22(18)	19.0			19.0	20
* Dev	± 4.0	**1.0**			**1.0**	**2.0**
#50		8.8			8.8	11.0
#100		5.0			5.0	6.6
*#200	1.8-5.8(3.8)	3.9			3.9	5.2
*Dev	± 2.0	**0.1**			**0.1**	**1.4**
Gradation Compliance?		Yes			Yes	Yes
DBR	0.6 - 1.4	0.92			0.92	1.23
% +4 Type 4	80	100.0			100.0	107.6
% +4 Type 3	45				0.0	
(+4/-4) Type 2	(25/0)	31.0/09.2			31.0/09.2	30.2/9.3

BINDER

	Target	Actual	Spec	Comply?
% Added Binder	3.70	3.82	N/A	
% Total Binder	4.70	4.80	4.40-5.00	Yes
% RAP	29.00	30.03%	≤100%	Yes
% RAS				
% Binder Replacement	20.07%	20.36%	≤ 30%	Yes
PG Grade	64-28		64-28	Yes

Gb: 1.01826 Gsb: 2.734 Pbe (%): 4.24

COMPACTED JOINT

Core ID	Lane	G_{mb}	Pa (%) (Gmm=2.565)
1-			
1-			
1-			
1-			
2-			
2-			
2-			
2-			
3-			
3-			
3-			
3-			
Average Pa (%)			

USE D.O.T. RESULTS
(Enter an 'X')

TEST STRIP
(Enter an "X")

FILM THICKNESS (FT) [8.0-15.0]	
FT, µm	**9.7**
Price Adjustment	$0.00

Gyratory VMA [13.0-15.0]	
VMA, %	**13.0**

QUANTITY FOR PAYMENT

Mix Unit Price ($/ton)	$48.55
Binder Unit Price ($/ton)	$686.20
Tons of Mix on Road	290.06
Tons to Other Bid Item(s)	
Tons of Binder	13.90
Tons of Waste	14.62
Tons of Binder to Date	13.90
Tons of Mix to Date	290.06

PLACEMENT RECORD

From Station	To Station	Lane	Width (ft)
271+95	253+42	SB/WB Pass Lr	12

Certified Tech: Taylor Maxfield Cert. No. EC593
Certified Tech: Dave McDowell Cert. No. EC898
Distribution: ____ Dist. Materials ____ Proj. Engineer ____ Contractor

COMPACTED MAT

Core	Station	CL Reference	W1 Dry (g)	W2 in H20 (g)	W3 Wet (g)	Diff.	G_{mb}	% of Gmm	P_a (%)	Thickness (in.)
1	268+95	6.3 S\W Pass	712.4	420.0	713.2	293.2	2.430	94.7	5.3	1.63
2	268+72	8.7 S\W Pass	613.9	367.4	614.1	246.7	2.488	97.0	3.0	1.38
3	265+07	6.4 S\W Pass	654.0	387.0	654.2	267.2	2.448	95.4	4.6	1.38
4	262+63	7.0 S\W Pass	850.0	499.8	850.2	350.4	2.426	94.6	5.4	1.75
5	259+52	5.4 S\W Pass	841.4	498.3	842.1	343.8	2.447	95.4	4.6	1.75
6	256+10	3.1 S\W Pass	846.9	499.6	847.4	347.8	2.435	94.9	5.1	1.75
7										
8										

Course Placed: Surface (Travel Lane) Thickness QI: 1.61
Intended Lift Thickness: 1.50 Avg. Mat Density: 2.446
Date Placed: 09/08/13 Avg. % of Gmm: 95.333
Test Date/By: 09/08/13 Mike Bloom Avg. % Field Voids: 4.67

$$\text{Q.I. (lower)} = \frac{(0.965 \times 2.565) - 2.446}{0.023} = \mathbf{1.27} \rightarrow \text{PWL (lower)} = 90.3$$

$$\text{Q.I. (upper)} = \frac{2.446 - (0.915 \times 2.565)}{0.023} = \mathbf{4.31} \rightarrow \text{PWL (upper)} = 100.0$$

$$\text{PWL (total)} = 90.3 + 100.0 - 100.0 = \mathbf{90.3}$$

Article 2303.03,E Applies for 300 ton plan quantity.

Field Voids Price Adjustment = $0.00

TEMPERATURE, °F

Time	7:00	9:00	11:00	1:00	3;00	5:00	7:00	Spec	Comply?
Air Temp	83	76							
Binder Temp	300	300						260-330 °F	Yes
Plant Temp	320	309						245-330 °F	Yes
Mat Temp				293	296	295		245-330 °F	Yes

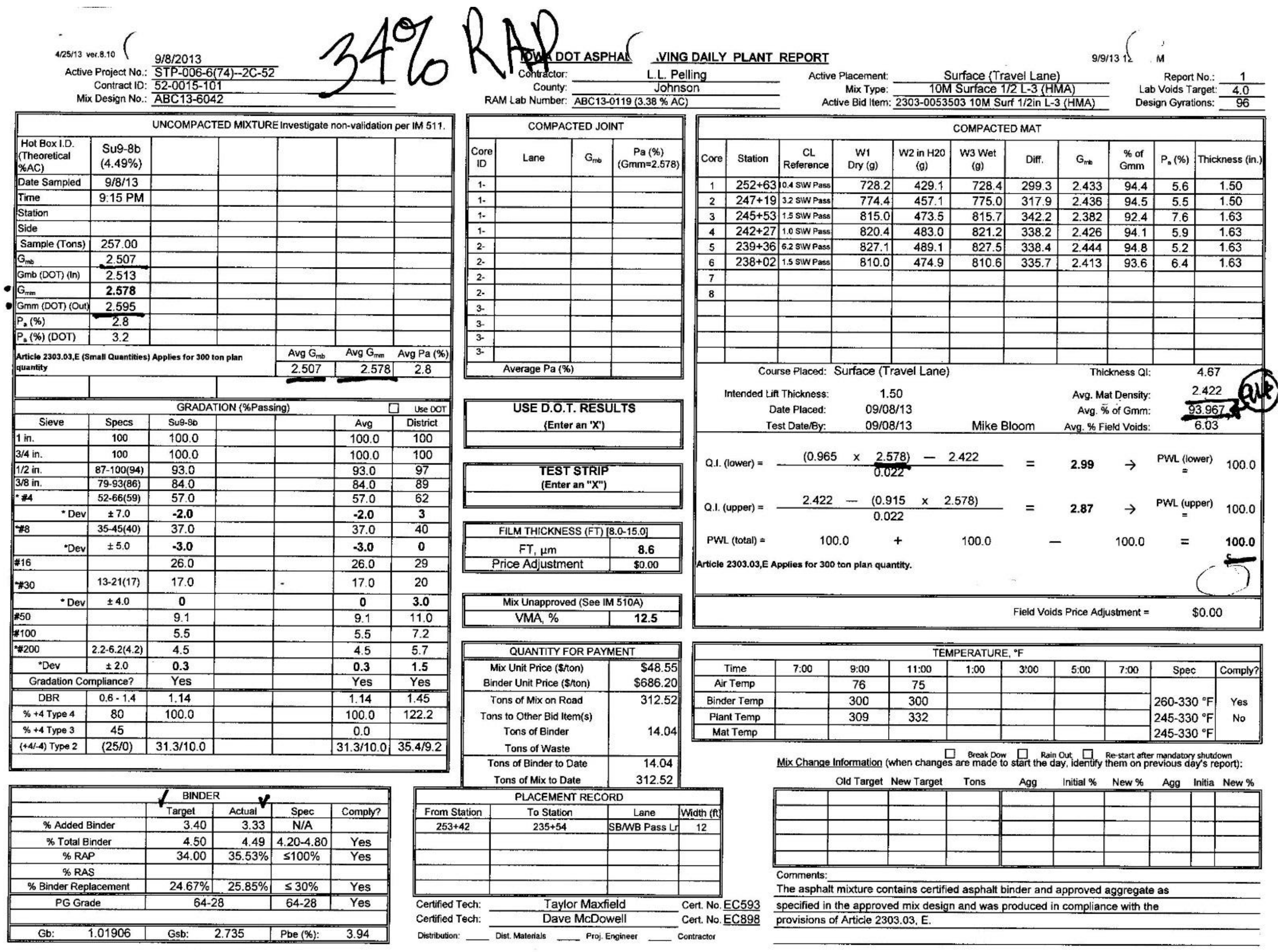
☐ Break Dow ☐ Rain Out ☐ Re-start after mandatory shutdown

Mix Change Information (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 asphalt mixture contains certified asphalt binder and approved aggregate as specified in the approved mix design and was produced in compliance with the provisions of Article 2303.03, E.

FIGURE B1: Plant Report for 30.0% RAP.



34% RAP

4/25/13 ver.8.10

IOWA DOT ASPHAL ,VING DAILY PLANT REPORT

9/9/13 12 M

Active Project No.: 9/8/2013 STP-006-6(74)--2C-52
Contract ID: 52-0015-101
Mix Design No.: ABC13-6042

Contractor: L.L. Pelling
County: Johnson
RAM Lab Number: ABC13-0119 (3.38 % AC)

Active Placement: Surface (Travel Lane)
Mix Type: 10M Surface 1/2 L-3 (HMA)
Active Bid Item: 2303-0053503 10M Surf 1/2in L-3 (HMA)

Report No.: 1
Lab Voids Target: 4.0
Design Gyrations: 96

UNCOMPACTED MIXTURE Investigate non-validation per IM 511.

Hot Box I.D. (Theoretical %AC)	Su9-8b (4.49%)					
Date Sampled	9/8/13					
Time	9:15 PM					
Station						
Side						
Sample (Tons)	257.00					
G_{mb}	2.507					
Gmb (DOT) (In)	2.513					
G_{mm}	2.578					
Gmm (DOT) (Out)	2.595					
P_a (%)	2.8					
P_a (%) (DOT)	3.2					

Article 2303.03,E (Small Quantities) Applies for 300 ton plan quantity

Avg G_{mb}	Avg G_{mm}	Avg Pa (%)
2.507	2.578	2.8

GRADATION (%Passing) ☐ Use DOT

Sieve	Specs	Su9-8b			Avg	District
1 in.	100	100.0			100.0	100
3/4 in.	100	100.0			100.0	100
1/2 in.	87-100(94)	93.0			93.0	97
3/8 in.	79-93(86)	84.0			84.0	89
* #4	52-66(59)	57.0			57.0	62
* Dev	± 7.0	-2.0			-2.0	3
*#8	35-45(40)	37.0			37.0	40
*Dev	± 5.0	-3.0			-3.0	0
#16		26.0			26.0	29
*#30	13-21(17)	17.0		-	17.0	20
* Dev	± 4.0	0			0	3.0
#50		9.1			9.1	11.0
#100		5.5			5.5	7.2
*#200	2.2-6.2(4.2)	4.5			4.5	5.7
*Dev	± 2.0	0.3			0.3	1.5
Gradation Compliance?		Yes			Yes	Yes
DBR	0.6 - 1.4	1.14			1.14	1.45
% +4 Type 4	80	100.0			100.0	122.2
% +4 Type 3	45				0.0	
(+4/-4) Type 2	(25/0)	31.3/10.0			31.3/10.0	35.4/9.2

BINDER

	Target	Actual	Spec	Comply?
% Added Binder	3.40	3.33	N/A	
% Total Binder	4.50	4.49	4.20-4.80	Yes
% RAP	34.00	35.53%	≤100%	Yes
% RAS				
% Binder Replacement	24.67%	25.85%	≤ 30%	Yes
PG Grade	64-28		64-28	Yes

Gb: 1.01906 Gsb: 2.735 Pbe (%): 3.94

COMPACTED JOINT

Core ID	Lane	G_{mb}	Pa (%) (Gmm=2.578)
1-			
1-			
1-			
1-			
2-			
2-			
2-			
2-			
3-			
3-			
3-			
3-			
Average Pa (%)			

USE D.O.T. RESULTS (Enter an 'X')

TEST STRIP (Enter an "X")

FILM THICKNESS (FT) [8.0-15.0]	
FT, µm	8.6
Price Adjustment	$0.00

Mix Unapproved (See IM 510A)	
VMA, %	12.5

QUANTITY FOR PAYMENT

Mix Unit Price ($/ton)	$48.55
Binder Unit Price ($/ton)	$686.20
Tons of Mix on Road	312.52
Tons to Other Bid Item(s)	
Tons of Binder	14.04
Tons of Waste	
Tons of Binder to Date	14.04
Tons of Mix to Date	312.52

PLACEMENT RECORD

From Station	To Station	Lane	Width (ft)
253+42	235+54	SB/WB Pass Ln	12

Certified Tech: Taylor Maxfield Cert. No. EC593
Certified Tech: Dave McDowell Cert. No. EC898
Distribution: ____ Dist. Materials ____ Proj. Engineer ____ Contractor

COMPACTED MAT

Core	Station	CL Reference	W1 Dry (g)	W2 in H20 (g)	W3 Wet (g)	Diff.	G_{mb}	% of Gmm	P_a (%)	Thickness (in.)
1	252+63	0.4 S\W Pass	728.2	429.1	728.4	299.3	2.433	94.4	5.6	1.50
2	247+19	3.2 S\W Pass	774.4	457.1	775.0	317.9	2.436	94.5	5.5	1.50
3	245+53	1.5 S\W Pass	815.0	473.5	815.7	342.2	2.382	92.4	7.6	1.63
4	242+27	1.0 S\W Pass	820.4	483.0	821.2	338.2	2.426	94.1	5.9	1.63
5	239+36	6.2 S\W Pass	827.1	489.1	827.5	338.4	2.444	94.8	5.2	1.63
6	238+02	1.5 S\W Pass	810.0	474.9	810.6	335.7	2.413	93.6	6.4	1.63
7										
8										

Course Placed: Surface (Travel Lane)
Intended Lift Thickness: 1.50
Date Placed: 09/08/13
Test Date/By: 09/08/13 Mike Bloom

Thickness QI: 4.67
Avg. Mat Density: 2.422
Avg. % of Gmm: 93.967
Avg. % Field Voids: 6.03

$$\text{Q.I. (lower)} = \frac{(0.965 \times 2.578) - 2.422}{0.022} = \mathbf{2.99} \rightarrow \text{PWL (lower)} = 100.0$$

$$\text{Q.I. (upper)} = \frac{2.422 - (0.915 \times 2.578)}{0.022} = \mathbf{2.87} \rightarrow \text{PWL (upper)} = 100.0$$

$$\text{PWL (total)} = 100.0 + 100.0 - 100.0 = \mathbf{100.0}$$

Article 2303.03,E Applies for 300 ton plan quantity.

Field Voids Price Adjustment = $0.00

TEMPERATURE, °F

Time	7:00	9:00	11:00	1:00	3:00	5:00	7:00	Spec	Comply?
Air Temp		76	75						
Binder Temp		300	300					260-330 °F	Yes
Plant Temp		309	332					245-330 °F	No
Mat Temp								245-330 °F	

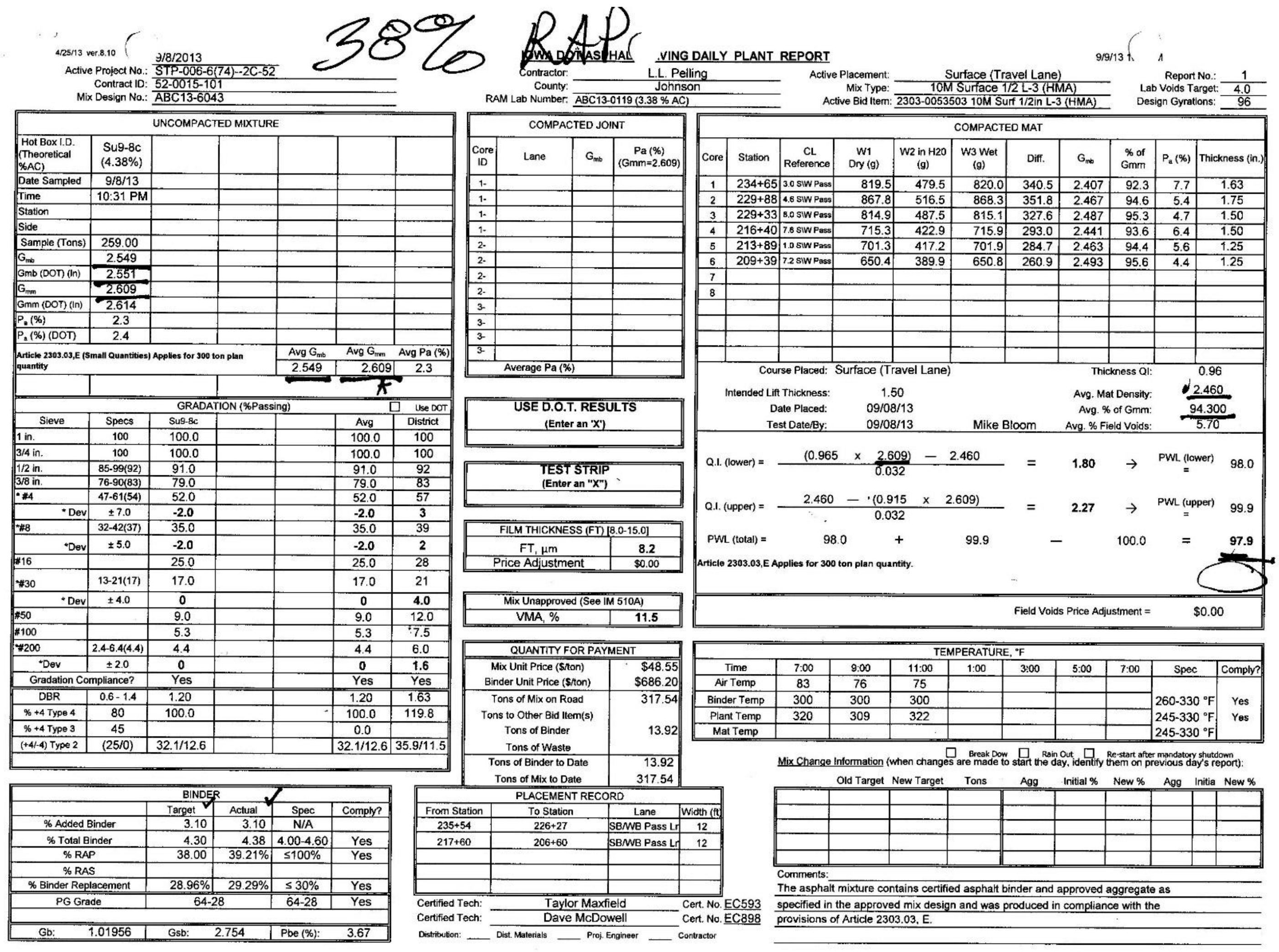
☐ Break Dow ☐ Rain Out ☐ Re-start after mandatory shutdown

Mix Change Information (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 asphalt mixture contains certified asphalt binder and approved aggregate as specified in the approved mix design and was produced in compliance with the provisions of Article 2303.03, E.

FIGURE B2: Plant Report for 35.5% RAP.



4/25/13 ver.8.10

38% RAP

OWA DOT ASPHAL .VING DAILY PLANT REPORT

9/9/13

9/8/2013
Active Project No.: STP-006-6(74)--2C-52
Contract ID: 52-0015-101
Mix Design No.: ABC13-6043

Contractor: L.L. Pelling
County: Johnson
RAM Lab Number: ABC13-0119 (3.38 % AC)

Active Placement: Surface (Travel Lane)
Mix Type: 10M Surface 1/2 L-3 (HMA)
Active Bid Item: 2303-0053503 10M Surf 1/2in L-3 (HMA)

Report No.: 1
Lab Voids Target: 4.0
Design Gyrations: 96

UNCOMPACTED MIXTURE

Hot Box I.D. (Theoretical %AC)	Su9-8c (4.38%)					
Date Sampled	9/8/13					
Time	10:31 PM					
Station						
Side						
Sample (Tons)	259.00					
G_{mb}	2.549					
Gmb (DOT) (In)	2.551					
G_{mm}	2.609					
Gmm (DOT) (In)	2.614					
P_a (%)	2.3					
P_a (%) (DOT)	2.4					

Article 2303.03,E (Small Quantities) Applies for 300 ton plan quantity

Avg G_{mb}	Avg G_{mm}	Avg Pa (%)
2.549	2.609	2.3

GRADATION (%Passing) ☐ Use DOT

Sieve	Specs	Su9-8c			Avg	District
1 in.	100	100.0			100.0	100
3/4 in.	100	100.0			100.0	100
1/2 in.	85-99(92)	91.0			91.0	92
3/8 in.	76-90(83)	79.0			79.0	83
* #4	47-61(54)	52.0			52.0	57
* Dev	± 7.0	**-2.0**			**-2.0**	**3**
*#8	32-42(37)	35.0			35.0	39
*Dev	± 5.0	**-2.0**			**-2.0**	**2**
#16		25.0			25.0	28
*#30	13-21(17)	17.0			17.0	21
* Dev	± 4.0	**0**			**0**	**4.0**
#50		9.0			9.0	12.0
#100		5.3			5.3	7.5
*#200	2.4-6.4(4.4)	4.4			4.4	6.0
*Dev	± 2.0	**0**			**0**	**1.6**
Gradation Compliance?		Yes			Yes	Yes
DBR	0.6 - 1.4	1.20			1.20	1.63
% +4 Type 4	80	100.0			100.0	119.8
% +4 Type 3	45				0.0	
(+4/-4) Type 2	(25/0)	32.1/12.6			32.1/12.6	35.9/11.5

BINDER

	Target	Actual	Spec	Comply?
% Added Binder	3.10	3.10	N/A	
% Total Binder	4.30	4.38	4.00-4.60	Yes
% RAP	38.00	39.21%	≤100%	Yes
% RAS				
% Binder Replacement	28.96%	29.29%	≤ 30%	Yes
PG Grade	64-28		64-28	Yes

Gb: 1.01956 Gsb: 2.754 Pbe (%): 3.67

COMPACTED JOINT

Core ID	Lane	G_{mb}	Pa (%) (Gmm=2.609)
1-			
1-			
1-			
1-			
2-			
2-			
2-			
2-			
3-			
3-			
3-			
3-			
Average Pa (%)			

USE D.O.T. RESULTS
(Enter an 'X')

TEST STRIP
(Enter an "X")

FILM THICKNESS (FT) [8.0-15.0]	
FT, µm	**8.2**
Price Adjustment	$0.00

Mix Unapproved (See IM 510A)	
VMA, %	**11.5**

QUANTITY FOR PAYMENT

Mix Unit Price ($/ton)	$48.55
Binder Unit Price ($/ton)	$686.20
Tons of Mix on Road	317.54
Tons to Other Bid Item(s)	
Tons of Binder	13.92
Tons of Waste	
Tons of Binder to Date	13.92
Tons of Mix to Date	317.54

PLACEMENT RECORD

From Station	To Station	Lane	Width (ft)
235+54	226+27	SB/WB Pass Lr	12
217+60	206+60	SB/WB Pass Lr	12

Certified Tech: Taylor Maxfield Cert. No. EC593
Certified Tech: Dave McDowell Cert. No. EC898
Distribution: ____ Dist. Materials ____ Proj. Engineer ____ Contractor

COMPACTED MAT

Core	Station	CL Reference	W1 Dry (g)	W2 in H20 (g)	W3 Wet (g)	Diff.	G_{mb}	% of Gmm	P_a (%)	Thickness (in.)
1	234+65	3.0 S\W Pass	819.5	479.5	820.0	340.5	2.407	92.3	7.7	1.63
2	229+88	4.6 S\W Pass	867.8	516.5	868.3	351.8	2.467	94.6	5.4	1.75
3	229+33	8.0 S\W Pass	814.9	487.5	815.1	327.6	2.487	95.3	4.7	1.50
4	216+40	7.6 S\W Pass	715.3	422.9	715.9	293.0	2.441	93.6	6.4	1.50
5	213+89	1.0 S\W Pass	701.3	417.2	701.9	284.7	2.463	94.4	5.6	1.25
6	209+39	7.2 S\W Pass	650.4	389.9	650.8	260.9	2.493	95.6	4.4	1.25
7										
8										

Course Placed: Surface (Travel Lane)
Intended Lift Thickness: 1.50
Date Placed: 09/08/13
Test Date/By: 09/08/13 Mike Bloom

Thickness QI: 0.96
Avg. Mat Density: 2.460
Avg. % of Gmm: 94.300
Avg. % Field Voids: 5.70

$$\text{Q.I. (lower)} = \frac{(0.965 \times 2.609) - 2.460}{0.032} = \mathbf{1.80} \rightarrow \text{PWL (lower)} = 98.0$$

$$\text{Q.I. (upper)} = \frac{2.460 - (0.915 \times 2.609)}{0.032} = \mathbf{2.27} \rightarrow \text{PWL (upper)} = 99.9$$

$$\text{PWL (total)} = 98.0 + 99.9 - 100.0 = \mathbf{97.9}$$

Article 2303.03,E Applies for 300 ton plan quantity.

Field Voids Price Adjustment = $0.00

TEMPERATURE, °F

Time	7:00	9:00	11:00	1:00	3:00	5:00	7:00	Spec	Comply?
Air Temp	83	76	75						
Binder Temp	300	300	300					260-330 °F	Yes
Plant Temp	320	309	322					245-330 °F	Yes
Mat Temp								245-330 °F	

☐ Break Dow ☐ Rain Out ☐ Re-start after mandatory shutdown

Mix Change Information (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 asphalt mixture contains certified asphalt binder and approved aggregate as specified in the approved mix design and was produced in compliance with the provisions of Article 2303.03, E.

FIGURE B3: Plant Report for 39.2% RAP.

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