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16. Abstract

This report summarizes the work conducted on Project 0-6682 up to August 31, 2013. The report is organized in five chapters corresponding to separate tasks in the project work plan, as follows:

- Chapter 1 presents the summary of the findings from the literature review.
- Chapter 2 presents the plan for the accelerated pavement testing.
- Chapter 3 reports on the establishment of the accelerated pavement testing facility.
- Chapter 4 presents the results of the laboratory testing conducted to design the mixes.
- Chapter 5 presents the construction of the hot mix asphalt layers and provides results of the in-situ tests done during construction.

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VALIDATION OF THE MAXIMUM ALLOWABLE AMOUNTS OF RECYCLED BINDER, RAP, AND RAS USING ACCELERATED PAVEMENT TESTING—INTERIM REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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EXECUTIVE SUMMARY

In recent years, recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS) have been widely used in hot mix asphalt (HMA) in several TxDOT districts since RAP and RAS can significantly reduce the cost of asphalt mixtures, conserve energy, and protect the environment. There is substantial speculation that the recent introduction of higher RAP and RAS contents to mixes prescribed in TxDOT standard specification Item 341, Dense-Graded Hot-Mix Asphalt (QC/QA), has had a negative impact on the life of HMA overlays.

The concern is that the recycled materials will make mixes stiffer and more prone to early cracking. As TxDOT moves into more and more RAP and RAS usage with different mix types (stone matrix asphalt, fine permeable friction course, and Superpave, to name a few), it is necessary to learn from the experiences of the past 3 to 4 years and define new directions to best use the "black gold" in Texas mixes.

This project conducted accelerated testing of mixes containing these recycled materials to verify if they are truly more crack susceptible, if the balance mix design approach can be used to mitigate problems, and if accelerated pavement testing can be effective at looking at the consequences of changes to the mix design process.

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CHAPTER 1. LITERATURE REVIEW

1.1 SUMMARY OF FINDINGS

An extensive literature review was conducted.

- The literature appears slanted toward the use of higher and higher RAP contents, but this is no doubt industry driven; recent performance studies from Texas and elsewhere have found constructability and cracking problems with higher recycled binder contents designed using current design methodologies.
- The proviso given in all claims is “properly designed mixes will perform equally,” but it is never defined what is a properly designed mix.
- Although the Texas Department of Transportation (TxDOT) has acknowledged the need for a cracking test to be run at the mix design stage for over 10 years, there is now a nationwide acceptance for this same need.
- The blending chart approach is an attempt to help mitigate cracking issues, but it is no substitute for the balanced design approach.
- There is no long-term performance data on recycled asphalt shingle (RAS) mixes, but the lab data are troubling; RAS, especially tear-offs because of the highly aged binder content, could be problematic.
- Only one accelerated performance test (APT) was conducted at the National Center for Asphalt Technology (NCAT) to evaluate mixes containing recycled asphalt pavement (RAP). However, NCAT did not evaluate the fatigue cracking performance of the mixes.

1.2 BACKGROUND

RAP has successfully been used for more than 30 years; if designed under established mixture design procedures and produced under appropriate quality control/quality assurance (QC/QA) measures, asphalt mixtures incorporating RAP perform comparably to conventional mixtures. The current national guideline for determining the binder grade adjustment in hot mix asphalt (HMA) mixes incorporating RAP require:

- No change in binder grade for RAP content less than 15 percent.
- The use of a virgin binder one grade softer than normal for RAP content between 15 and 25 percent.
- The determination of the virgin binder grade using blending charts for RAP content more than 25 percent.

However, many states have decided to change these limits to adapt to local conditions. Several studies compared the performances of virgin and recycled asphalt pavements and found them to be similar.

The use of RAS in asphalt mixes has started relatively recently. Therefore, there is no published information on in-service performance of mixes incorporating RAS. Also, no mix design method specifically addresses the incorporation of RAS alone, or with RAP, in recycled asphalt mixes.

RAP/RAS mixes are generally stiffer than virgin mixes. Thus, it is anticipated that RAP/RAS mixes are more rutting resistant but may be prone to cracking. Therefore, it is very challenging to design mixes with such stiff RAP/RAS materials. Either softening agents or rejuvenators should be considered to lower the performance grade (PG) of the RAP/RAS binder. To improve the durability, the use of the balanced mix design approach is proposed in addition to the three approaches already tried or discussed by TxDOT: increasing design density, reducing recycling asphalt binder content, and using softer binders.

Because of the reduced temperature during mixing in the drum for warm mix asphalt (WMA) produced with RAP and RAS, the virgin binder may not blend homogeneously with the recycled asphalt binder from RAP/RAS, creating an educated belief that the melting of the asphalt in the RAP/RAS particles is greatly reduced and does not supply the amount of liquid asphalt required. Coupled with the fact that 13 approved WMA technologies are currently available in Texas, the efficiency of incorporation of RAP/RAS in WMA mixes is of great concern.

1.3 DESIGN OF ASPHALT MIXTURES CONTAINING RAP

The current national guideline for determining the binder grade adjustment in HMA mixes incorporating RAP is given in Table 1.1 (*1*). Some state transportation departments have modified the range of percentages (e.g., increased the RAP percentage that can be used before a softer binder grade must be chosen) based on conditions in that area and/or additional testing.

Table 1.1. Binder Selection Guidelines for RAP Mixtures According to American Association of Highway and Transportation Officials (AASHTO) M 323 (*1*).

Recommended Virgin Asphalt Binder Grade	RAP Percent in the mix, by weight
No change in binder selection	< 15
Select virgin binder one grade softer than normal (e.g., select PG 58-28 if PG 64-22 would normally be used)	15–25
Follow recommendations from blending charts	> 25

For percentages of RAP greater than 25 percent, procedures for developing a blending chart are provided in the appendix of AASHTO M 323 (*1*). Two options are addressed:

1. When the desired final blended binder grade, the desired percentage of RAP, and the recovered RAP binder properties are known, the required properties of the appropriate virgin binder grade can be determined according to blending chart procedures.
2. When a specific virgin asphalt binder grade must be used and the desired blended binder grade and recovered RAP properties are known, the allowable percentage of RAP is determined according to blending chart procedures.

It is important to note that the earlier blending charts recommended by Kandhal and Mallick (*2*) are based on the viscosity or rutting factor, G*/sin(delta), of the virgin binder and of the binder in the RAP. The charts rely on a linear relationship between the percent RAP that should be used and the log of viscosity or rutting factor.

The more recent blending charts, like those included in AASHTO M 323, use the critical temperatures (high, intermediate, or low) of the binders. For Option 1 above, the required properties of a virgin binder grade are determined at each temperature (high, intermediate, and low) separately as follows:

$$T_{virgin} = \frac{T_{blend} - (\%RAP \times T_{RAP})}{(1 - \%RAP)}$$

Where:
T_{virgin} = Critical temperature of virgin asphalt binder (high, intermediate, or low).
T_{Blend} = Critical temperature of blended asphalt binder (final desired; high, intermediate, or low).
$\%RAP$ = Percentage of RAP expressed as a decimal.
T_{RAP} = Critical temperature of recovered RAP binder (high, intermediate, or low).

For Option 2, the allowable RAP percentage can be determined as follows:

$$\%RAP = \frac{T_{blend} - T_{virgin}}{T_{RAP} - T_{virgin}}$$

This should be determined at high, intermediate, and low temperatures. The RAP content or range of contents meeting all three temperature requirements should be selected.

The blending chart process is time consuming, involves hazardous solvents, and creates disposal issues. It assumes complete blending between the virgin and RAP aggregate and assumes that RAP is uniform in terms of binder grade and content. Therefore, some alternative procedures have been proposed:

- *Based on an assumed stiffness of the binder in the RAP.* Using the high temperature grade of the virgin asphalt binder as the high temperature grade at 0 percent RAP, the RAP content versus high temperature binder grade can be plotted to estimate the effect of the RAP on stiffness, specifically the high temperature binder grade (see Figure 1.1). For example, in the Southeast and Mid-Atlantic regions, researchers have determined that asphalt in the RAP usually has a high temperature grade between 88 and 94°C. Thus, when using 100 percent RAP, it is assumed that the high temperature grade is 92°C. This procedure is simple and may work well because many state transportation departments have standardized the PG binder grade for HMA on a regional, project type, and/or program basis in lieu of determining the binder grade for the specific project location and application.
- *Based on a mix dynamic modulus.* The methodology developed by Bonaquist (*3*) involves measuring the mix dynamic modulus, |*E**|, of several mixes containing RAP. In addition to this, the binder is extracted and recovered from the mix, during which the virgin and RAP binders become totally blended. The shear modulus (*G**) of the recovered binder is measured using the dynamic shear rheometer (DSR). The recovered binder's *G** value is used as input into the Hirsch model or the modified Witczak model to estimate the mix |*E**|, which is referred to as estimated |*E**|. The estimated |*E**| is compared to the measured |*E**|, and if the data match, it is assumed there is good blending of the virgin and RAP binders. The procedure that uses |*E**| of the mix to determine the RAP PG

binder grade is not recommended for individual mix designs. It represents an option for studies on which state transportation department requirements for selection of virgin binder grade may be established. Procedures based on similar concepts are recommended by Stephens et al. (*4*) and by Zofka et al. (*5*), but they utilize the Indirect Tension Test and the Bending Beam Rheometer test, respectively.

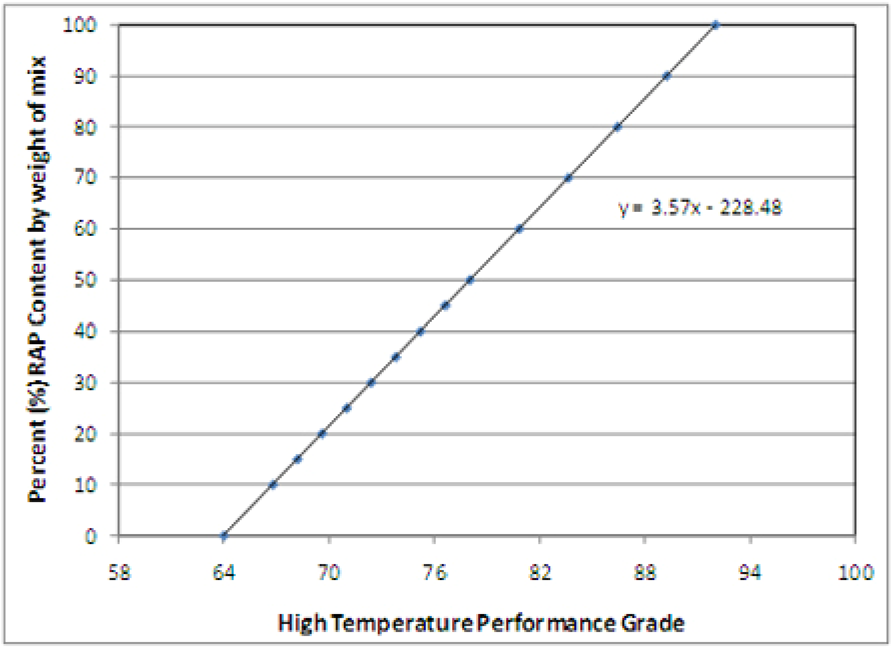

Figure 1.1. Percent RAP Content versus High Temperature PG.

None of the mix design procedures recommended above include performance tests, for rutting or cracking, for example. Therefore, it seems that the success of the design of mixes containing more than 25 percent RAP relies on local experience developed from the performance of previous projects constructed utilizing RAP.

However, it is generally recommended that performance tests should be conducted to determine if the designed mix has sufficient resistance to rutting, moisture damage, fatigue, and thermal cracking. A variety of performance tests is available. Table 1.2 provides recommended tests for each distress mechanism (*6*).

Table 1.2. Performance Tests for Asphalt Mixtures.

Distress Mechanism	Test Description	Standard
Permanent deformation	Asphalt pavement analyzer	AASHTO TP63 (discontinued)
	Hamburg wheel tracking device	AASHTO T 324
	Repeated load triaxial creep (flow number using asphalt mixture performance tester [AMPT])	AASHTO TP79
Moisture sensitivity	Tensile strength ratio	AASHTO T 283
	Hamburg wheel tracking device (wet)	AASHTO T 324
Fatigue	Four-point bending beam fixture	AASHTO T 321
	Dynamic modulus—continuum fatigue damage (push/pull)	NCHRP 9-29 updated continuum fatigue damage software for AMPT
Thermal cracking	Thermal stress restrained specimen test	No standard available
	Indirect tensile test	No standard available

1.4 PERFORMANCE OF ASPHALT MIXTURES CONTAINING RAP

The long-term performance of recycled asphalt pavements, particularly when compared to conventional HMA performance, has not been well documented. State transportation departments that routinely used RAP in HMA production were convinced of its benefits, possibly other than performance, and that recycled asphalt pavement performance was comparable to conventional HMA performance. As a result, long-term pavement performance (LTPP) information has not been routinely collected. RAP is primarily used in base and intermediate pavement layers precluding the use of surface condition evaluations and visual observation techniques to assess performance.

In Louisiana, Paul (*7*) evaluated the field performance of conventional and recycled asphalt pavements that were 6–9 years old. He analyzed the pavements for condition, serviceability, and structural analysis. The RAP sections contained 20–50 percent RAP. He found no significant difference in terms of the pavement conditions and serviceability ratings.

NCAT completed a study comparing virgin and recycled asphalt pavements using data from the LTPP program (*8*). Data from 18 projects across the United States were analyzed to compare paired sections of virgin asphalt mix and recycled asphalt mix containing 30 percent RAP. The projects ranged from 6 to 17 years. The distress parameters that were considered were rutting, fatigue cracking, longitudinal cracking, transverse cracking, block cracking, and raveling. An analysis of variance (ANOVA) test indicated that performance of the recycled and virgin sections were statistically different for fatigue, longitudinal cracking, and transverse cracking, where the virgin sections performed slightly better than the RAP sections. Additional statistical analyses using paired *t*-tests showed that the RAP mixes performed better than or equal to the virgin mixes for the majority of the locations for each distress parameter. Table 1.3 summarizes the statistical analyses results for each distress parameter and shows that RAP performed equal to (i.e., insignificant difference between RAP and virgin mix, Column 4) or better than (Column 3) virgin mixes as a majority percentage (Column 5). NCAT concluded that in most cases, using 30 percent RAP in an asphalt pavement can provide the same overall performance as virgin asphalt pavement.

Table 1.3. Summary of Statistical Analyses from NCAT LTPP Study (*8*).

Distress Parameter	Virgin Performed Significantly Better than RAP (Percent)	RAP Performed Significantly Better than Virgin (Percent)	Insignificant Difference Between RAP and Virgin (Percent)	RAP Performed Equal to or Better than Virgin (Percent)
IRI	42	39	19	58
Rutting	33	29	38	67
Fatigue cracking	29	10	61	71
Longitudinal cracking	15	10	75	85
Transverse cracking	32	15	53	68
Block cracking	3	1	96	97
Raveling	7	15	78	93

In a separate analysis by the Federal Highway Administration's (FHWA's) LTPP program to determine the impact of design features on performance, the majority of the 18 sites did not show significant differences in performance between sections overlaid with virgin and recycled mixes (*9*).

Hong et al. (*10*) also investigated the LTPP-specific pavement studies' Category 5 test sections in Texas with 35 percent RAP. The performance monitoring period in Texas covered 16 years from 1991 to 2007, and the performance indicators included transverse cracking, rut depth, and ride quality (i.e., international roughness index [IRI]). The high RAP sections were compared to virgin sections. Overall, both types of sections had satisfactory performance over the performance monitoring period. Compared with the virgin pavement sections, the sections with high RAP had higher cracking amounts, less rut depth, and similar ride quality (i.e., roughness) change over time. Based on the analysis of field data in this study, Hong et al. (*10*) concluded that pavement constructed with 35 percent RAP, if designed properly, can perform well and as satisfactorily as a virgin pavement during a normal pavement life span.

The California Department of Transportation (Caltrans) performed a comparative analysis of 47 RAP sections and 7 other different treatments (located within a reasonable distance on the same route) in 3 different environmental zones (*11*). Caltrans allowed up to 15 percent RAP to be substituted for virgin aggregate, which is the assumed RAP content for the sections analyzed in this study. Comparisons were made for the following indices: in-situ structural capacity, distress condition, roughness condition, and construction consistency. The long-term performance of RAP was found and expected to be comparable to the other treatments based on deterioration models.

The Florida Department of Transportation (FDOT) took a random sampling of mix designs with more than 30 percent RAP content (RAP content ranged from 30 to 50 percent) (*12*). The pavements were constructed between 1991 and 1999, and the age when the pavements became deficient was noted. The only distress parameter considered in the analyses was cracking because it is Florida's most common mode of distress. The average life of virgin mixtures is 11 years. For 30, 35, 40, 45, and 50 percent RAP content mixes, the average age ranges from 10 to 13 years. The primary conclusion of the study was that there does not appear to be a significant difference in pavement life and performance between 0 and 30 percent RAP (*12*).

The most recent summary of the use of RAP in the Unites States is FHWA Report FHWA-HRT-11-021, "Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice" (*13*). The report contains a summary of the usage of RAP, but not much information is provided on the design methods or the performance experience in the states. However, it is highlighted that the RAP is increasingly used by most states and that many states have used more than 30 percent RAP in the mixes.

A summary of state specifications can be found at the MoreRAP website (*14*). However, this information was collected in 2005 and therefore needs to be updated to reflect current practice.

1.5 FIELD PERFORMANCE OF RAP/RAS MIXES IN TEXAS AND NATIONWIDE

In recent years, RAP and RAS have been widely used in HMAs in several TxDOT districts since they can significantly reduce the cost of asphalt mixtures, conserve energy, and protect the environment. However, now there is substantial speculation that the recent introduction of higher RAP and RAS contents to TxDOT's Item 341 mixes has had a negative impact on the life of HMA overlays. In particular, the concern is that these cycled materials will make mixes stiffer and more prone to early cracking.

The Houston District commented that the average overlay life now appears to be less than 5 years, whereas in the past, the district counted on at least 8 years for a new overlay. No hard data are available to substantiate these claims. As TxDOT moves into more and more RAP/RAS usage with different mix types (e.g., stone matrix asphalt [SMA], fine permeable friction course [PFC], Superpave), it is necessary to learn from the experiences of the past 3 to 4 years and then define new directions to best use the "black gold" in Texas mixes.

Project 0-6682 conducted accelerated testing of mixes containing these recycled materials to verify if they are truly more crack susceptible, if the balance mix design approach can be used to mitigate problems, and if accelerated pavement testing can be effective at looking at the consequences of changes to the mix design process.

RAP/RAS mixes are generally stiffer than virgin mixes. Thus, it is anticipated that the RAP/RAS mixes are more rutting resistant, but they may be prone to cracking, which would compare to the findings in Texas and the United States.

Recently, West et al. (*15*) compared the performance of RAP mixes with virgin mixes. Asphalt overlay sections of Specific Pavement Study Experiment 5 (SPS5) built in 18 states and provinces in North America between 1989 and 1998 were reviewed. Seven distress parameters from these test pavements were analyzed, including IRI, rutting, fatigue cracking, longitudinal cracking, transverse cracking, block cracking, and raveling. West et al. found that:

- Overlays with mixes that contained 30 percent RAP were found to perform as well as overlays with virgin mixes in terms of IRI, rutting, block cracking, and raveling.
- In terms of fatigue cracking and transverse (reflective) cracking, virgin mixes edged the 30 percent RAP mixes.
- Thicker overlays improved pavement performance, except for rutting. Milling before rehabilitation decreased IRI, fatigue cracking, and transverse cracking but increased rutting.

Hong et al. (*10*) specifically reviewed the SPS5 asphalt overlay sections on US 175 near Dallas. Similar findings were observed:

- With everything else the same, an asphalt overlay with 35 percent RAP mix has half of the life of an overlay with virgin mix in terms of transverse (reflective) cracking.
- In terms of rutting, 35 percent RAP mix is more rut resistant, and its rut depth is 70 percent that of the virgin mix.
- If well designed (i.e., using 3 percent latex on US 175), 35 percent RAP mixes can perform similar to the virgin mixes.

In the last 4 years, many asphalt overlay sections were constructed with RAP mixes. Figure 1.2 shows a 2-year-old asphalt overlay section on IH 35W. Severe reflective cracking was observed. Additionally, four test sections were constructed on IH 40 in Amarillo under TxDOT Research Project 0-6092. These four sections are (1) a 0 percent RAP control section with a contractor designed mix, (2) a 20 percent RAP section with a contractor designed mix, (3) a 20 percent RAP section with a Texas A&M Transportation Institute (TTI) designed mix (higher asphalt binder), and (4) a 35 percent RAP section with a TTI designed mix (softer binder and higher asphalt content). After 2 years in service, all sections had no measurable rutting but very visible reflective cracking. So far, the 35 percent RAP section has showed the least reflective cracking. The main conclusion from the IH 40 test sections is that the RAP mixes can be designed to have similar (or even better) performance compared to virgin mixes, but they must meet certain rutting and cracking requirements.

In summary, RAP/RAS mixes normally have better rutting resistance but poor cracking resistance. Meanwhile, RAP/RAS mixes need to and can be designed to have similar performance to that of virgin mixes by such things as increasing design density and using softer binder. So far no data are available for the performance of SMA, PFC, and Superpave mixes with RAP/RAS in Texas. Furthermore, the impact of WMA technologies on performance of RAP/RAS mixes should be investigated as well.

Figure 1.2. A 2-Year-Old Asphalt Overlay with RAP Mixes on IH 35W North of Alvarado.

1.6 SPECIFICATION COMPARISON BETWEEN TEXAS AND OTHER STATES

Currently, most states allow the use of RAP in HMA, but not all states allow the use of RAS. Texas is one of the states allowing both RAP and RAS including tear-offs. Texas is in the process of renewing the specification, making it more useful to compare Texas' specification with other states. For simplicity, only the states allowing both RAP and RAS including tear-offs are listed in Tables 1.4 to 1.9. A review of these specifications shows that the current Texas specification falls within the range of the maximum allowable RAP/RAS usage but close to the maximum limits. The upcoming new specification may lower the maximum allowable recycled binder.

Table 1.4. Texas Specification.

Mixture Description & Location	Maximum Ratio of Recycled Binder[1] to Total Binder (%)	Maximum Allowable % (Percentage by Weight of Total Mixture)		
		Unfractionated RAP[2]	Fractionated RAP[3]	RAS[4]
Surface Mixes[5]	35	10	20	5
Non-Surface Mixes[6] < 8 in. from Final Riding Surface	40	15	30	5
Non-Surface Mixes[6] > 8 in. from Final Riding Surface	45	20	40	5

1. Combined recycled binder from RAP and RAS.
2. Do not use in combination with RAS or fractionated RAP.
3. May not be used in addition to unfractionated RAP; however, up to 5 percent of fractionated RAP may be replaced with RAS.
4. May be used separately or as a replacement for no more than 5 percent of the allowable fractionated RAP.
5. *Surface mixes* are defined as mixtures that will be the final lift or riding surface of the pavement structure.
6. *Non-surface mixes* are defined as mixtures that will be an intermediate or base layer in the pavement structure.

Table 1.5. Alabama Specification.

Mix	Maximum Allowable % (Percentage by Weight of Total Aggregates)			
	Combined RAP and RAS	RAP	Tear-off RAS	Manufacture Waste RAS
Surface	15	20	3	5
Intermediate	20	25	3	5
Bituminous base	20	25	3	5

Table 1.6. Georgia Specification.

Plant	Maximum Allowable % (Percentage by Weight of Total Mixture)			
	Combined RAP and RAS	RAP	Tear-off RAS	Manufacture Waste RAS
Drum plant	0	40	5	5
Batch plant	0	25	5	5

Note: Georgia requires that the combined virgin and recycled binder after rolling thin film oven (RTFO) conditioning have an absolute viscosity at 60°C between 600 and 1600 Pa·s.

Table 1.7. Minnesota Specification.

Traffic Level (MESAL)	Maximum Allowable % (Percentage by Weight of Total Mixture)					
	RAP		Tear-off RAS		Manufacture Waste RAS	
	Surface	Lower	Surface	Lower	Surface	Lower
<1	30	40	5	5	5	5
1 to <3	30	30	5	5	5	5
3 to <10	30	30	0	5	5	5
10 to <30	30	30	0	0	5	5

Table 1.8. Missouri Specification.

Maximum Allowable % (Percentage by Weight of Total Mixture)	
RAP	**RAS**
Up to 20% RAP of the mixture without changing the grade of virgin binder	7% RAS in mixtures without changing the grade of the binder provided the binder replacement is less than 30%
Greater than 20% RAP is permitted provided a blending chart analysis shows the blended binder meets the specified performance grade	

Note: Missouri specification does not address combining RAP and RAS in the same mixture.

Table 1.9. Virginia Specification.

Mix	Max. Allowable Binder Replacement for Mixtures with Both RAP and RAS	Maximum Allowable % (Percentage by Weight of Total Mixture)	
		RAP	RAS
Surface	25	30	5
Intermediate	25	30	5
Bituminous base	25	35	5

1.7 CHARACTERIZATION OF RAP/RAS PROPERTIES

Extensive studies have been conducted under Research Projects 0-6092 and 0-6614 to characterize RAP/RAS properties including RAP/RAS variability. RAP/RAS stockpiles were sampled around the state, and the laboratory test results showed that both fractionated RAP and the processed RAS are consistent in terms of aggregate gradation and asphalt binder content.

Additionally, the binder was extracted and recovered from the RAP/RAS. The main concern was the stiffness of the RAP/RAS binder, which was very variable. The high end of the PG grade of the RAP binders ranged from 82 to 115°C. The biggest concern was the RAS binder, as shown in Figure 1.3. These stiff RAP/RAS materials make it very challenging to design mixes. Either softening agents or rejuvenators should be considered to lower the PG of the RAP/RAS binder.

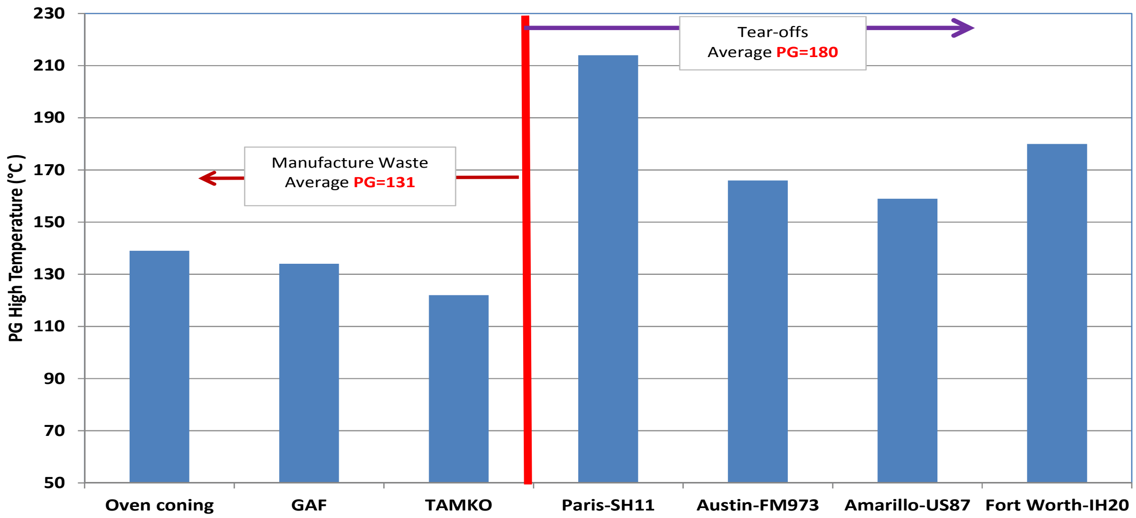

Figure 1.3. DSR Test Results of RAS Binders.

1.8 MIX DESIGN APPROACHES TO IMPROVING DURABILITY OF RAP/RAS MIXES

In the last several years, at least three approaches have been tried or discussed to improve the durability of the RAP/RAS mixes in Texas. The three approaches are (1) increasing the design density, (2) reducing the recycled asphalt binder content, and (3) using softer binders. The first approach has been implemented in the current specification. For example, the design density for a RAP/RAS mix has been increased from 96 percent to 97 percent for virgin dense-grade mixes. The other two approaches are being considered in the upcoming new specification. Currently, these three approaches are under evaluation in the laboratory and field test sections through Research Projects 0-6092 and 0-6614. Apparently, each approach will have a positive effect on the durability of the RAP/RAS mixes, but it is unknown as to what extent the improvement may be different. Therefore, it is necessary to investigate the cost-benefit of each approach in terms of field performance.

An alternative mix design is to use the balanced mix design approach (*17*) in which the Hamburg wheel tracking test (HWTT) and Overlay test are used to evaluate the rutting/moisture and cracking resistance of RAP/RAS mixes, respectively. Both the rutting/moisture damage and cracking resistance of RAP/RAS mixes can be assured through setting necessary requirements, as shown in Figure 1.4. For example, a minimum of 300 cycles of the Overlay test is required for SMA mixes regardless of the amount of RAP/RAS. More data are needed to develop different criteria for different mixes.

1.9 RAP/RAS MIXES PRODUCED WITH WMA TECHNOLOGIES

Currently, the use of RAP and RAS is also allowed with asphalt mixes produced with WMA technologies. WMA produced with RAP and RAS can significantly reduce the cost of asphalt mixtures, conserve energy, and protect our environment (*18, 19*). Additionally, the use of WMA technologies does help with compaction issues. However, recent studies have shown the virgin binder may not be blending homogeneously with the recycled asphalt binder from RAP/RAS even at production temperatures of 300°F and above.

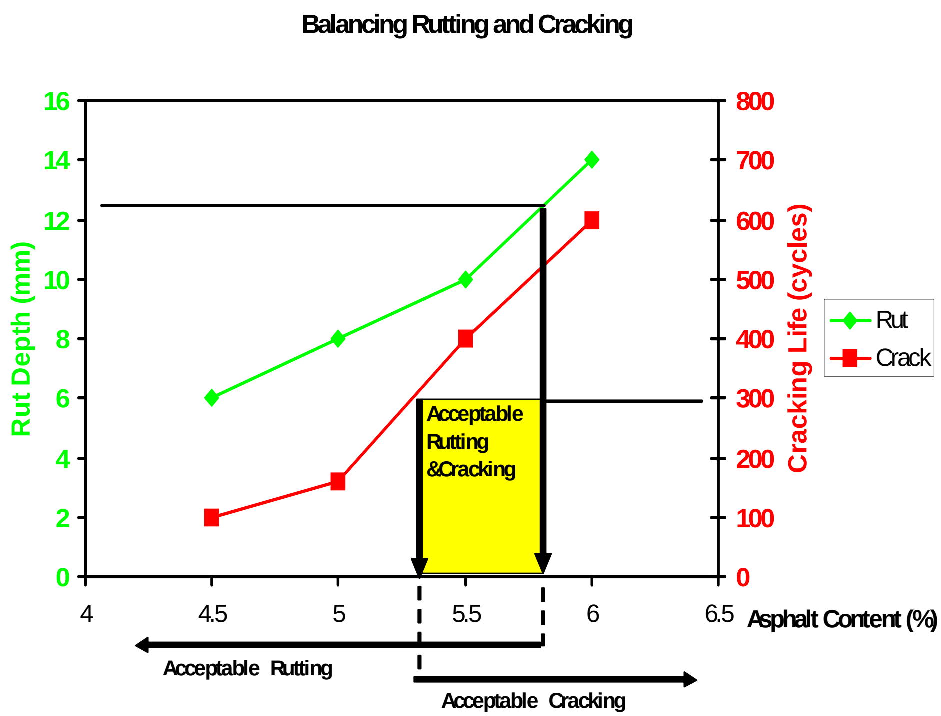

Figure 1.4. Hamburg, Overlay Tester, and Balanced Mix Design Concept.

Button et al. (*20*) demonstrated, using laboratory HMA mixtures, that manufacturing waste shingle particles appeared to sufficiently melt into the HMA. However, bundles of glass fibers were found still intact in the shape of a shredded shingle particle. It was recommended to increase the mixing and compaction temperatures to accommodate HMA mixtures containing shingles. Subsequent field studies by TxDOT, as Senadheera et al. (*21*) reported, further revealed that shingle tab trimmings (manufacturing waste) maintained their integrity after passing through an HMA mixing plant and being compacted in the mat. That is, some of the tab trimmings rose up from the compacted mat and still others became visible after trafficking/weathering.

The issue of non-homogeneous blending may become more severe and detrimental when WMA technologies and additives are required during production at the plant either for:

- Reducing emissions.
- Protecting the environment in nonattainment areas (such as Houston, Dallas/Fort Worth, Austin, San Antonio, El Paso, Longview, and other areas).
- Avoiding the expansion of rubber crack sealant materials with the placement of asphalt overlays.

Now, when RAP/RAS combines with WMA technologies, which utilize mixing temperatures significantly lower than those of HMA, there is even greater concern about successful melting of the RAP/RAS particles. This issue becomes even more complicated when dealing with up to 13 different WMA technologies (Table 1.10) with 3 types of processes (foaming process, chemical additive, and organic additive). Research is definitely needed to determine if RAP, particularly RAS including both manufacture waste and tear-offs, is appropriate for use in WMA with different processes.

Table 1.10. TxDOT Approved WMA Products and Technologies (9/1/2012).

WMA Technology	Process Type	WMA Supplier
Advera (Synthetic Zeolite)	Chemical Additive	PQ Corporation
Aspha-Min (Synthetic Zeolite)	Chemical Additive	Aspha-Min
Astech PER (Hydrogreen)	Chemical Additive	Meridian Technologies
Cecabase RT	Chemical Additive	Arkema Inc.
Double Barrel Green	Foaming Process	Astec Industries, Inc.
Evotherm	Chemical Additive	MeadWestvaco Asphalt Innovations
HydroFoam IEQ	Foaming Process	East Texas Asphalt Co., Ltd.
Rediset WMX	Chemical Additive	AkzoNobel Surface Chemistry
Rediset LQ 1106	Chemical Additive	AkzoNobel Surface Chemistry
Sasobit	Organic Additive	Sasol Wax Americas, Inc.
Terex	Foaming Process	Terex Roadbuilding
Maxam	Foaming Process	Maxam Equipment
Ultrafoam GX	Foaming Process	Gencor Industries

1.10 APT TESTING OF RAP AND RAS MIXES

An experiment at the NCAT Test Track studied both the constructability and performance of moderate and high RAP content mixes. Six test sections (see Tables 1.11 and 1.12) were incorporated into a RAP experiment during the 2006 Test Track. The six test sections were built in 2006 using a 2 inch (50 mm) mill and inlay with RAP mixtures. Beneath the RAP inlay was a 22 inch (560 mm) HMA structure on top of an aggregate base and track subgrade (*22*, *23*). The virgin control section was the mill/inlay placed on Section N5.

Quality control data showed slight deviations in both the air voids and voids filled with asphalt (VFA) in Test Sections W3, W4, and W5. The air void contents were approximately 2 percent, and the VFA percentages were about 10 percent higher than the design range for the heavily trafficked pavements. These discrepancies were attributed to differences in the gradations of the RAP stockpiles used for design and production (*22, 23*).

Table 1.11. RAP Sections in the 2006 Research Cycle.

Test Section	Study HMA (inches)	Surface Mix Stockpile Materials	Specified Binder	Research Objective(s)
E5	2	Grn/Lms/Snd (45% RAP)	PG67-22	RAP Mix Design/ Construction/Performance
E6	2	Grn/Lms/Snd (45% RAP)	PG76-22	RAP Mix Design/ Construction/Performance
E7	2	Grn/Lms/Snd (45% RAP)	PG76-22s	RAP Mix Construction/ Performance w/ Sasobit
W3	2	Grn/Lms/Snd (20% RAP)	PG76-22	RAP Mix Design/ Construction/Performance
W4	2	Grn/Lms/Snd (20% RAP)	PG67-22	RAP Mix Design/ Construction/Performance
W5	2	Grn/Lms/Snd (45% RAP)	RA500	RAP Mix Design/ Construction/Performance

Note: All sections are newly reconstructed; Design Methodology = Superpave; Total HMA = 24 inches; Base Material = Granite; Subgrade = Stiff.

Table 1.12. Summary of Test Sections and Binder Test Data (*22, 23*).

Section	%RAP*	%RAP Binder**	Virgin Binder		Virgin Binder + RAP	
			PG Grade	True Grade	Predicted Grade	Recovered Grade
W3	20	18.2	PG 76-22	78.1 -23.8	80.1 -22.4	78.1 -30.3
W4	20	17.6	PG 67-22	68.4-31.2	72.0 -28.6	74.2 -29.7
W5	45	42.7	PG 52-28	54.7-32.8	69.4 -25.8	74.1 -30.2
E5	45	41.0	PG 67-22	68.4-31.2	76.9 -25.1	80.9 -26.2
E6	45	41.9	PG 76-22	78.1-23.8	82.7 -20.7	85.5 -25.7
E7	45	42.7	PG 76-22 +1.5% Sasobit	83.2 -20.6	85.7 -18.8	86.3 -24.3
N5	0	0	PG 67-22	68.4-31.2	68.4 -31.2	71.1 -32.4

*by weight of aggregates; **by weight of binder

During construction, the 20 percent RAP test sections were easily compacted under the first few roller passes. Compactability of the 45 percent RAP test sections was influenced by the asphalt binder grade. The sections with the softest binder exhibited the least compaction resistance. The two sections that required the most compaction effort were the 45 percent RAP sections containing the PG 76-22 binder and the PG 76-22 + Sasobit. The Sasobit was added to aid in compaction, not for the reduction in production temperature. However, the additive did not appear to improve the compactability of the RAP mat.

When considering the field and laboratory test results from this study, the following conclusions were inferred (*22, 23*):

- Overall binder stiffness has an impact on the compactability of RAP mixes in the field.
- Despite low air voids and high VFA, the RAP mixes performed well in the field at the NCAT Test Track in regard to rutting.
- The minor cracking in the test sections in the RAP experiment was not related to the structural properties of the RAP mixture.
- With the exception of the virgin test mix, rutting results from the asphalt pavement analyzer (APA) matched the field rut measurements.
- Master curves show that binder stiffness greatly influences mix stiffness. Softer grades of binder decrease the mix stiffness, which could decrease a pavement's durability.
- Differences in beam fatigue results appear to be more affected by binder volume content than by binder stiffness.
- Based upon laboratory and field data collected at the NCAT Test Track, there does not appear to be a strong case for supporting the use of softer binder grades in high RAP mixes.

It is important to comment that, as expected, the field experiment showed that the RAP mixes had very good rut resistance and high stiffness, but no fatigue cracking could be observed because of the very thick asphalt and strong pavement structure (24 inches [610 mm] of HMA on top of a granite base on a stiff subgrade). However, the conclusion relating to the fatigue cracking resistance of the mixes was drawn solely based on the beam fatigue tests conducted on the reheated plant mix following AASHTO T 321-07. The tests were conducted on long-term aged specimens at 20°C and a constant strain of 500 microstrain. Failure was considered at a 50 percent reduction in stiffness with original stiffness determined at the 50th loading cycle. The results are given in Figure 1.5.

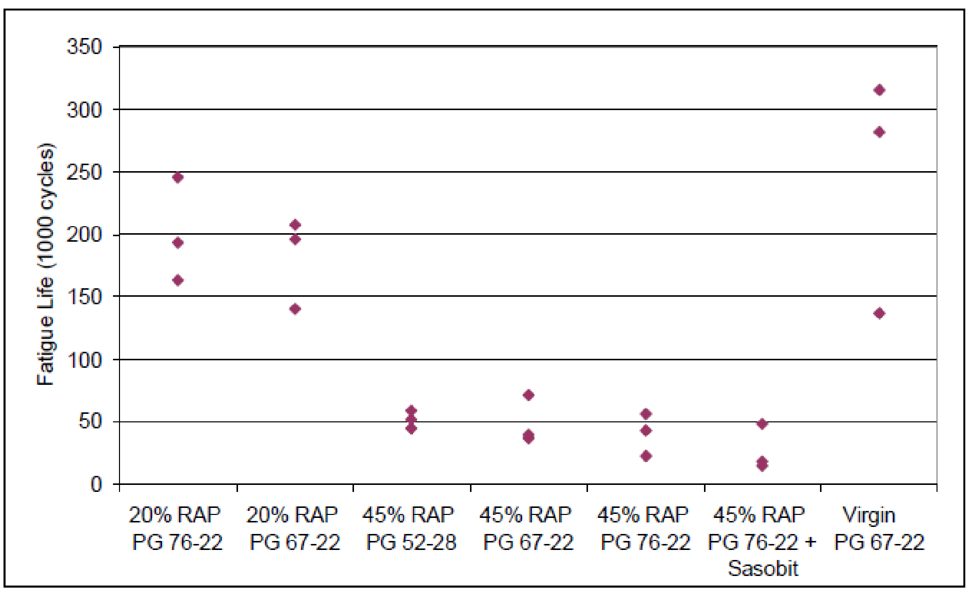

Figure 1.5. Beam Fatigue Lives for the RAP Mixes (*22, 23*).

It is clear from the figure that too few samples were tested to properly conduct an ANOVA analysis. Thus, it cannot be concluded that the mix with 20 percent RAP has similar fatigue resistance as the mix with no RAP. As expected, the increase from 20 percent to 45 percent in the RAP content significantly reduced the fatigue resistance of the mix.

As part of a study investigating the performance of mixes with RAP and RAS conducted by the Minnesota Department of Transportation (MnDOT) (*24*), six experimental cells at MnROAD had pavement shoulders built with asphalt mixes containing RAP or RAS, both from manufacturing waste RAS and tear-off RAS. The study observed several other in-service field sections of such mixes, but all of them were on low volume roads not at the MnROAD site. None of the field sections were built in the mainline of medium or high volume roads because the objective of the study was to investigate the constructability, rutting, and thermal cracking performance of these mixes; thermal (low temperature) cracking heavily influences the durability of Minnesota HMA pavements.

Even though the fatigue cracking performance of the mixes and no specific design methods for mixes containing RAP and/or RAS were investigated in this study, several findings are worth mentioning (*24*):

- The minimum limit of 70 percent for the ratio between the new binder to total binder was confirmed.
- Moisture sensitivity tests (Lottman) conducted on RAP/RAS mixtures failed to meet current MnDOT specifications only for the tear-off RAS.
- Mixes containing 5 percent tear-off RAS had visibly higher stiffness than the mixes containing 5 percent manufacturing waste RAS.
- A control section comprised of PG 58-28 binder and no RAS/RAP performed similarly to a section comprised of PG 52-34 binder and 10 percent tear-off RAS.
- Laboratory preparation methods generally achieved greater mixing between the recycled and virgin binders, which yielded stiffer mixtures than comparable plant produced mixtures.

Field observation of several in-service test sections built in several states with mixes containing RAS was conducted as part of the Pooled Fund Study TPS-5(213). However, after 2 years of performance monitoring, the results obtained so far are not very promising (*24*).

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CHAPTER 2. DETAILED PLANNING OF THE APT EXPERIMENT

A detailed plan for the APT experiment was submitted in November 2012. The plan contains the detailed description of the pavement structures and asphalt mixes to be tested in this project, the quality control of asphalt mixes, the proposed accelerated testing program, the embedded instrumentation, the pavement performance and response monitoring, and the post-mortem analysis.

2.1 PROPOSED PAVEMENT STRUCTURES

The plan for the research experiment includes the proposed configuration and location of the experimental pavement structures as well as the type of mix used for each layer; these details are given in Table 2.1 and Figure 2.1. The configuration of the pavement structures and the mix designs were approved by the Project Monitoring Committee (PMC). A meeting of the research team took place with Austin Bridge and Road (ABR) before the paving was conducted to discuss any concerns and to highlight all the requirements of this project, which included:

- Asphalt mix composition must be the same as specified in the job mix formula (JMF) for each mix. Sufficient quantities of each mix must be produced to obtain a uniform mix.
- Layer thickness must be as close as possible to the nominal layer thicknesses given in Table 2.1.
- Construction work must satisfy all TxDOT specification requirements for asphalt mixes (except smoothness).

2.2 PROPOSED MIX DESIGNS

The proposed mix designs for the asphalt mixes to be placed on the experimental sections were described in detail in a separate technical memorandum submitted to the TxDOT project director. The mix designs are also given in Chapter 4 of this report. The mix designs were approved by the PMC.

2.3 MATERIAL COLLECTION AND LABORATORY TESTING

As specified in the plan of the experiment, asphalt mix samples were obtained during and after construction to determine the properties of the as-constructed asphalt concrete layers. Samples of raw materials were obtained to determine:

- For aggregate, on material sampled from stockpiles:
    - Gradation.
    - LA abrasion.
    - Coarse and fine aggregate angularity.
    - Percent particles smaller than 0.075 mm.
- For bituminous binders:
    - Shear modulus (G*) and phase angle at 20°C, 40°C, 58°C, 64°C, and 70°C.
    - PG gradation of binder used.

Table 2.1. Configuration of the Pavement Structures in the APT Experiment.

Test Section	*Reflection Cracking Experiment*			*Fatigue Cracking Experiment*			
	Surface 2.0 in.	Intermediate 2.0 in.	Base 8.0 in.	Test Section	Surface 2 in.	Base 8.0 in.	Subbase 8.0 in.
A	Type D	Type C	Cement (3.5%) Treated Base	L	Type D	Bridgeport Rock	Cement (2.0%) Treated Subbase
B	High RAP	Type C		E	High RAP		
C	RAP&RAS	Type C		F	RAP&RAS		
D	BMD	Type C		G	BMD		

Test Section	*Rutting Experiment* Surface 2.0 in.	Intermediate 6.0 in.	Base 7.0 in.
H	Type D	Type B	Cement (3.5%) Treated Base
I	High RAP	High RAP	
J	RAP&RAS	High RAP	
K	BMD	High RAP	

High RAP
RAP&RAS
BMD = Balanced Mix Design
Type D
Type C
These mixes and designs are subject to modification based on PMC review

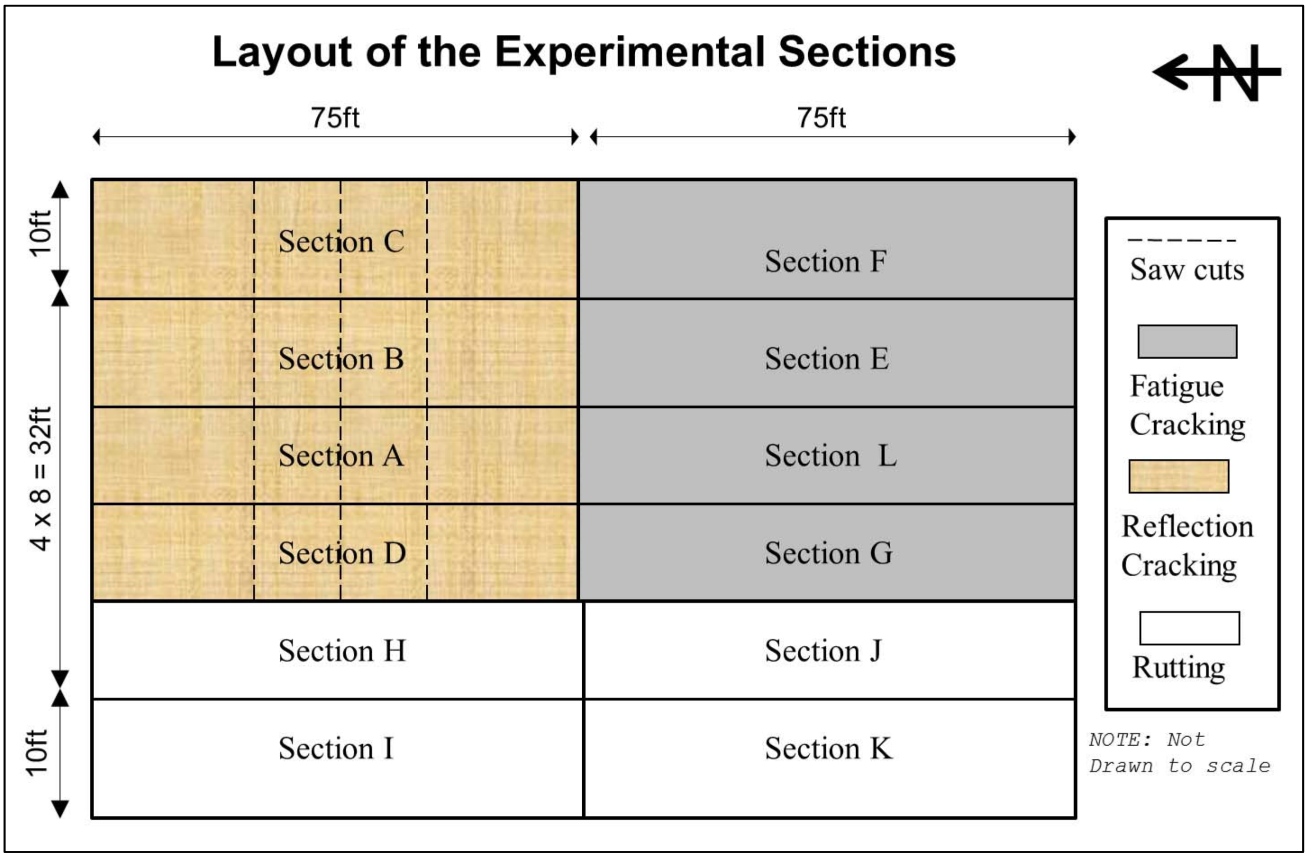

Figure 2.1. Schematic Layout of the Experimental APT Sections.

- For the asphalt mixes collected during construction:
  - Binder content.

- Aggregate gradation.
- Rutting resistance with the HWTT on laboratory compacted samples and on cut cores.
- Cracking resistance with the Overlay Tester (OT) on laboratory compacted samples and on cut cores.
- Fatigue resistance on beams (two strain levels, one temperature 20°C, two replicates).
- Permanent Deformation Test as required by TTI's Overlay design program.
- Dynamic modulus at two temperatures (20°C and 40°C).

Sufficient quantities of aggregates and asphalt binder were also be obtained and stored for future testing as needed. These materials may be made available to both Construction Division personnel and other TxDOT researchers if approved by the PMC.

2.4 QUALITY CONTROL OF ASPHALT LAYER CONSTRUCTION

As specified in the plan of the experiment, the following were done during construction to ensure the quality of asphalt concrete mixes:

- A Pave-IR bar was mounted on the back of the lay down machine to check mat thermal uniformity.
- Ground penetrating radar (GPR) was used after compaction to test for section uniformity, both thickness and density.
- In coordination with the GPR, data field cores were extracted to check mat uniformity and thickness.
- Nuclear density gauges were run to ensure an acceptable within-specification mat air void content was being achieved.
- Sufficient HMA samples were taken for all future lab tests.
- A falling weight deflectometer (FWD) test was run shortly after construction to provide all of the required inputs for the modeling, including the load transfer on the saw cut sections.

2.5 FULL-SCALE ACCELERATED PAVEMENT TESTING

The plan of the experiment indicates the following regarding the full-scale testing of the experimental pavement structures:

- The fatigue cracking and reflection cracking pavement sections will be tested at a target temperature of ±20°C (±68°F), while the testing of the rutting pavement sections will be conducted at a target temperature of ±40°C (±104°F). The temperature control chamber already built on the machine will control the temperature at 0.5 inches from the pavement surface at a desired level within ±2.5°C (±5°F).
- Bi-directional trafficking will be applied for the fatigue cracking and rutting pavement sections, while uni-directional trafficking will be applied for the reflection cracking pavement sections.
- An 18,000 lb (81.6 kN) single axle load and a tire inflation pressure of 100 psi (690 kPa) will be used throughout this experiment. The axle load and tire inflation pressure will be kept the same during the entire duration of the experiment. The tire inflation pressure will

be checked every four weeks. The axle load value will be measured at the same time with the pavement response measurements. The pavement testing machine (PTM) is equipped with load cells to measure the load applied by each of the two wheels of the axle. A load profile is normally measured at the same time with the strain measurements.

- The lateral position of the PTM will be changed during testing such that it will follow a normal distribution with a standard deviation of 8 inches and a maximum lateral position of 12 inches. This way, the lateral wonder follows a normal distribution truncated at the 87^{th} percentile (6.5 percent on each tail).
- Accelerated loading will be applied until at least one of the following distress levels is reached:
  - 19 mm (0.75 inch) rut depth at the pavement surface.
  - 25 percent of each lane area is cracked (equivalent to 50 percent of the trafficked area cracked).

The plan of the experiment also presents an initial estimation of number of passes to failure under the loading of an 18-kip single axle dual tire. The estimated number of passes to failure is given in Table 2.2. These were best-guess estimates using assumed moduli values and the proposed layer thicknesses. These estimates will be revised once actual FWD data and as-built materials properties are available.

Table 2.3 shows the anticipated increase in reflection cracking life by placing mixes of different numbers of Overlay Tester cycles. These are based on estimates from the TxDOT Overlay design program, with assumed materials properties and LTE values. The Overlay Tester cycles from 50 to 250 seem appropriate from the first round of laboratory test results, with the high RAP/RAS mixes lasting around 50 cycles.

Table 2.2. Life Analysis of the Fatigue Sections.

Case	Surface	Flex Base		Treated Subbase		Subgrade	Cracking		Rutting	
	E_1 (ksi)	E_2 (ksi)	H_2 (in.)	E_3 (ksi)	H_3 (in.)	E_4 (ksi)	ε_T (x10^-6)	N_f (x10^6)	ε_V (x10^-6)	N_f (x10^6)
1	500	50	8	35	8	12	270	0.6	413	1.94
2	500	50	8	50	8	12	266	0.6	386	2.62
3	500	70	8	50	8	12	201	1.6	359	3.63
4	500	100	8	150	8	12	139	5.3	244	20.0

ε_T, ε_V—Transverse and longitudinal strains (microstrain).

Table 2.3. Life Estimates for Reflection Cracking Sections.

Overlay Tester Cycles	Estimated passes to 50% reflection cracking	% improvement
50	80,000	—
100	92,000	15%
250	121,000	51%

2.6 INSTRUMENTATION AND PAVEMENT RESPONSE AND PERFORMANCE MONITORING

The plan of the experiments provides the following details regarding the monitoring of pavement response and performance:

- The condition of the pavement as well as strains in the tested pavement structures will be monitored during the entire duration of the experiment. Transverse profiles will be measured on the test lanes at the beginning of the APT loading; after 0, 5,000, 25,000, 50,000, and 100,000 passes; and then at every 100,000 passes of the PTM axle. Three transverse profiles spaced at 8.0 ft intervals along each test section will be recorded using a transverse profiler. The transverse profile will consist of elevation data recorded at 0.5 inch spacing. The rut depth and permanent deformation values derived from the transverse profiles will be computed.
- After surface cracks are first observed, crack mapping will be performed at the same time with the profile measurements on the portion of the section where the axle travels at constant speed. The cracking extent and severity will be determined from the mapped data. The calculation of the percentage of area with fatigue cracking will be done for a grid with the size of the squared openings of 6 inches.
- Two transverse strain gauges and two longitudinal strain gauges were installed for all test sections during their construction. Strain measurements under the passing axle will be performed at 0, 5,000, 25,000, 50,000, and 100,000 passes and then at every 100,000 passes of the PTM axle. On the newly constructed pavements, strain measurements at two other temperatures than the testing temperature will be attempted. The location of the strain gauges is presented in Figures 2.2 and 2.3. A National Instruments data acquisition system was purchased and will be used to collect strain data at 1,000 Hz sampling rate.
- Eight thermocouples will be installed between the test sections to measure the temperature in two locations, at the surface of the pavement and at three depths within the asphalt layers. The temperature will be measured every 15 minutes. One TDR moisture sensor will be installed for each pair of test sections. Moisture and temperature data will be monitored periodically to ensure that the testing environment does not change to affect the performance of the pavement sections.

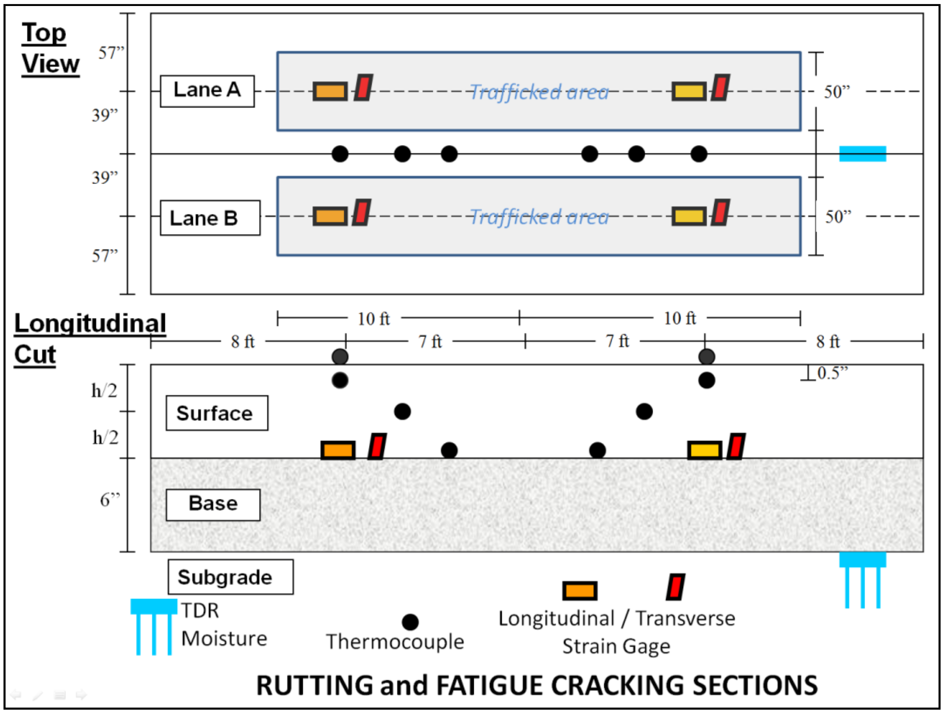

Figure 2.2. Instrumentation to Be Installed in the Rutting and Fatigue Cracking Sections.

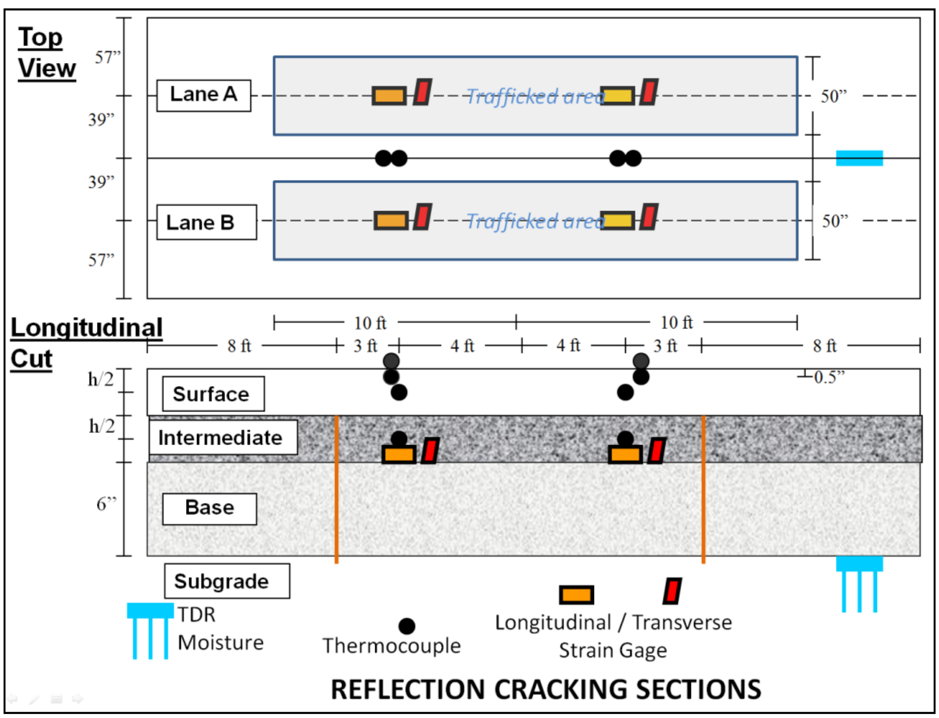

Figure 2.3. Instrumentation to Be Installed in the Reflection Cracking Sections.

2.7 NDT DATA COLLECTION

The plan of the research experiment indicates that FWD tests will be conducted by the TxDOT crew. The tests will be scheduled in consultation with the UT Arlington (UTA) research team. The FWD tests will be performed on the test lanes as follows:

- After construction of the lanes or right before loading is started.
- After 5,000 loading passes.
- After 100,000 loading passes.
- After loading is completed.

The FWD tests will be performed at three locations per lane, with drop configurations selected by the TxDOT crew and the UTA-TTI research team. The TxDOT crew will provide the deflection data to the UTA-TTI research team, who will be responsible for data processing and moduli backcalculation. Asphalt layer moduli will also be measured periodically with the Portable Seismic Pavement Analyzer (PSPA) device, with the goal of determining the deterioration of the asphalt concrete.

2.8 POST-MORTEM FORENSIC EVALUATION

The plan of the experiment indicates that the forensic evaluation of the tested lanes will be performed in order to investigate the failure mode and the causes of failure. After failure, one transverse trench will be cut in each test lane down to the level of the subgrade soil by TxDOT. The transverse profile at the top of the base layer and on top of the surface layer will be recorded to determine the contribution of the asphalt surface layer to the surface rutting. Coring of asphalt concrete will be performed in and outside the trafficked areas by TxDOT to obtain core samples that will be later used for material evaluation.

CHAPTER 3. ESTABLISHMENT OF THE APT FACILITY

The APT facility has been established entirely with UT Arlington internal funds. The facility is now fully functional. It is the only one of its kind in the State of Texas.

3.1 FACILITY LOCATION

The APT is being conducted at the Accelerated Pavement Research Facility (APRF) on a site near The University of Texas at Arlington's Research Institute (UTARI), near SH-820, about 1 mile north of I-30, on the east side of Fort Worth, Texas. The site is located less than a mile from an asphalt plant owned by Austin Bridge & Road Inc., the company that produced and placed the hot mix asphalt for the experimental test sections.

The aerial view of the site is shown in Figure 3.1. The trailer hosting the personnel offices and the 12 experimental pavement lanes to be tested in this project are visible.

Figure 3.1. Map Layout of the APRF Site in Ft. Worth.

The entire site is bordered by a chain-link fence and illuminated during nighttime by two light poles for security purposes. The site is provided with all needed utilities: electricity, water, and sewer lines. Internet and phone are available through a cellular modem.

3.2 FACILITY DESCRIPTION

Figure 3.2 shows a schematic of the APRF. The main components of the APRF are:

- The experimental test area or test pad is a 150 ft by 150 ft elevated area with 3 ft (0.9 m) of imported subgrade soil. A total of 30 experimental pavement sections, each 75 ft

(22.9 m) long and 8 ft (2.4 m) wide was constructed on top of the imported subgrade soil. Only 12 pavement sections have been built for this project.

- Parking and access areas around the experimental area provide sufficient space not only for parking but also for maneuvering of large construction equipment used in removing the existing sections and constructing new ones.
- There is an entry gate (sliding) on the east side and an equipment access gate on the north side of the site.
- A 70 ft (21.3 m) long and 14 ft (4.3 m) wide office trailer was purchased, brought to the site, and modified to satisfy the requirements of the work to be conducted at the APRF. An office room accommodates three desks and several filing cabinets. A research technician permanently works at this location. A large room can serve as a conference room or as an additional temporary office for students or visitors. A third room serves as a storage room for tools, materials, and equipment. The trailer is equipped with a bathroom and a kitchenette. The trailer has two entry doors toward the entry gate (east) and one toward the experimental test area.
- An electrical transformer with several disconnect switches placed to the south of the trailer provides electricity to the trailer and to the PTM.

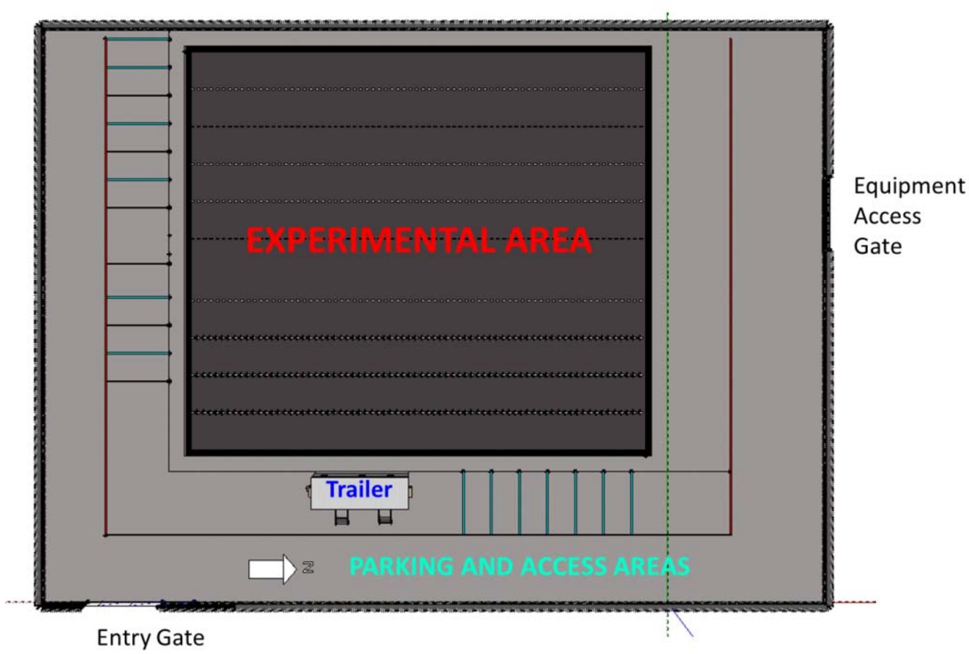

Figure 3.2. Schematic Diagram of APRF.

Figure 3.3 shows several photos of the APRF, while Figure 3.4 shows several photos of the interior of the personnel trailer.

Figure 3.3. Photos of the APRF.

Figure 3.4. Interior of the Personnel Trailer.

The APRF facility is entirely operational; all needed features are present and functioning properly. The connection to the Internet is done via cellular modem. A surveillance camera system is installed.

3.3 PAVEMENT TESTING MACHINE

The PTM has been built with all components installed and functional. After the calibration and several trial runs were completed, it was moved onto the experimental sections, and the accelerated testing has commenced. Figure 3.5 shows the interior and the exterior of the PTM. Figure 3.6 shows the PTM placed on top of the pair of rutting sections to be tested first.

Figure 3.5. Photos of the Pavement Testing Machine.

Figure 3.6. PTM Placed on Top of Rutting Sections J and K.

CHAPTER 4. HMA MIX DESIGNS

Research Project 0-6682 is and will be running accelerated pavement testing over test sections with four mixes containing different levels of RAP and RAS. The basic layout of the test sections is shown in Table 4.1.

Table 4.1. UTA Test Sections to Be Tested under APT Loading.

<table>
<tr><td rowspan="2">Test Section</td><td colspan="3">Reflection Cracking Experiment</td><td colspan="4">Fatigue Cracking Experiment</td></tr>
<tr><td>Surface 2.0 in.</td><td>Intermediate 2.0 in.</td><td>Base 8.0 in.</td><td>Test Section</td><td>Surface 2 in.</td><td>Base 8.0 in.</td><td>Subbase 8.0 in.</td></tr>
<tr><td>A</td><td>Type D</td><td rowspan="4">Type C</td><td rowspan="4">Cement (3.5%) Treated Base</td><td>L</td><td>Type D</td><td rowspan="4">Bridgeport Rock</td><td rowspan="4">Cement (2.0%) Treated Subbase</td></tr>
<tr><td>B</td><td>High RAP</td><td>E</td><td>High RAP</td></tr>
<tr><td>C</td><td>RAP&RAS</td><td>F</td><td>RAP&RAS</td></tr>
<tr><td>D</td><td>BMD</td><td>G</td><td>BMD</td></tr>
<tr><td colspan="4">Rutting Experiment</td><td colspan="4" rowspan="6">High RAP = (19% RAP)
RAP&RAS = (15%RAP + 3%RAS)
BMD = Balanced Mix Design
Type D contains no RAP
Type B and C mixes may or may not contain RAP
These mixes and designs are subject to modification based on PMC review</td></tr>
<tr><td>Test Section</td><td>Surface 2.0 in.</td><td>Intermediate 6.0 in.</td><td>Base 7.0 in.</td></tr>
<tr><td>H</td><td>Type D</td><td rowspan="4">Type B</td><td rowspan="4">Cement (3.5%) Treated Base</td></tr>
<tr><td>I</td><td>High RAP</td></tr>
<tr><td>J</td><td>RAP&RAS</td></tr>
<tr><td>K</td><td>BMD</td></tr>
</table>

The preliminary plan was to take locally available mixes that meet TxDOT's current Item 341 specification containing different levels of RAP and RAS. Three widely used ABR mixes were tested at TTI to see if they were suitable for use on the test sections.

4.1 LAB TEST RESULTS

Three ABR mix designs were modified slightly to meet the 2012 Item 341 mix design specifications. This included the use of a target 96.5 percent lab molded density and changes in the maximum amount of both RAP and RAS allowed. A Texas gyratory design was run on the three mixes with the results provided in the attached Excel spreadsheets, which include:

1. Control mix (Control 134tti.xls) with no RAP or RAS and a PG 64-22 binder with an optimum asphalt content (OAC) of 4.8 percent.
2. RAP mix (RAP 119tti.xls) with 19 percent RAP and OAC of 4.8 percent.
3. RAP/RAS mix (RAP-RAS196tti.xls) with 15 percent RAP and 3 percent RAS with an OAC of 5.0 percent. (In production, the contractor will have to place this using warm mix technology to meet the new specification requirement. At the contractor's choice, the warm mix additive Evotherm 3G was used.)

These three mixes were then run through the Hamburg and Overlay Tester performance tests to judge their suitability for testing under the PTM. A fourth mix was also tested; this was the first attempt to arrive at a balance mix design (BMD) with the RAP/RAS mix. The purpose of the

BMD was to adjust mix parameters so that the modified mix would have similar lab test results to the control mix. The performance test results for all four mixes are shown in Table 4.2.

Table 4.2. First Round of Tests on Proposed APT Mixes.

Design	% Rock				RAP %	RAS %	TD %	OAC %	LAS %	HWTT @10K	OT
	BPD	BPMS	MCMS	FS							
D134	61	-	30	9	-	-	96	5.0	1	-	-
D134 (TTI) Control	**61**	**-**	**30**	**9**	**-**	**-**	**96.5**	**4.8**	**1**	**Failed @4766**	**228**
D119	45	29	-	6	20	-	96	4.8	1	2.7	-
D119 (TTI)RAP	**46**	**29**	**-**	**6**	**19**	**-**	**96.5**	**4.8**	**1**	**10.7**	**122**
D196	48	29	-	5.6	15	3	97	5.1	1	5.4	-
D196 (TTI)RAS	**48**	**29**	**-**	**5.6**	**15**	**3**	**96.5**	**5.0**	**1**	**7.8**	**62**
D196 (TTI) BMD	**48**	**29**	**-**	**5.6**	**15**	**3**	**97.5**	**5.5**	**1**	**9.1**	**78**

Note: TTI results in bold text; ABR in normal text. BPD = Bridgeport D rock; BPMS = Bridgeport manufactured sand; MCMS = Mill Creek Man Sand; FS = Field Sand; LAS = Liquid Antistrip.

Before discussing these results, the following issues are important:

- The Bridgeport aggregates proposed for this project were of good quality, as can be seen below from the cut face shown in Figure 4.1. There is very little binder absorption and no crushing of the rocks. This rock has an LA abrasion of 27 and a magnesium sulfate soundness of 11, as reported in TxDOT's Bituminous Rated Source Catalog (8/06/13). Given the wide range of soundness values found in Texas for limestone, aggregates with a value less than 15 are considered to be the harder, potentially better-performing aggregates. Therefore, a value of 11 is considered by the research team to be a good quality material.
- The Hamburg samples stripped badly, as shown in Figure 4.2. The fines (looks like the field sand) from all of the mixes stripped out. This is also apparent in the Hamburg plots (Figure 4.3) for all mixes tested, raising questions about the value and effectiveness of the liquid antistrip used in this mix. However, as shown in Figure 4.4, the control mix did pass the boil test (Tex Method 530-c) with ease; no stripping or loss of coating was detected.

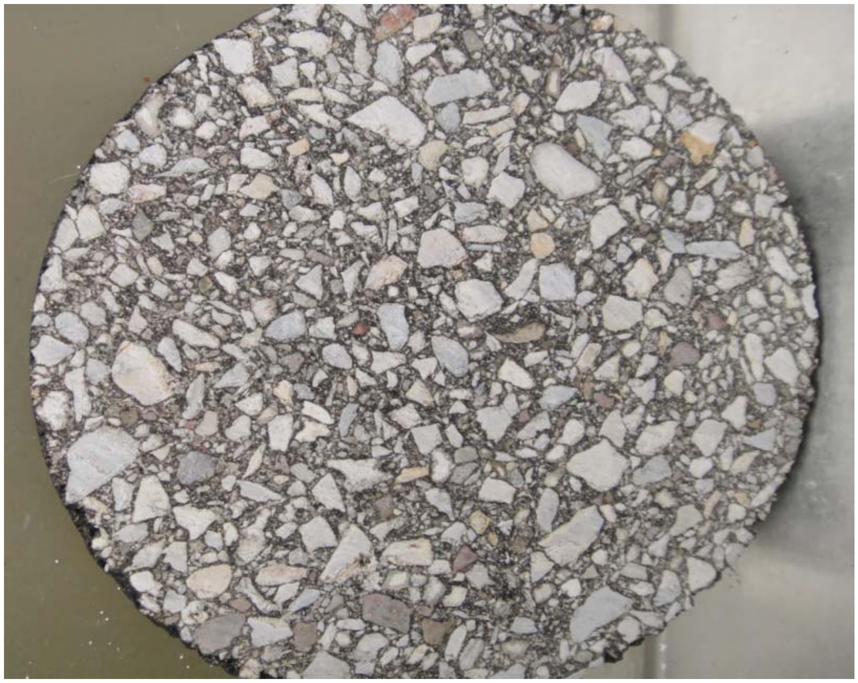

Figure 4.1. Cut Face of the 20 Percent RAP Mix.

Figure 4.2. Control Mix after Testing—Many Fines Stripped Out.

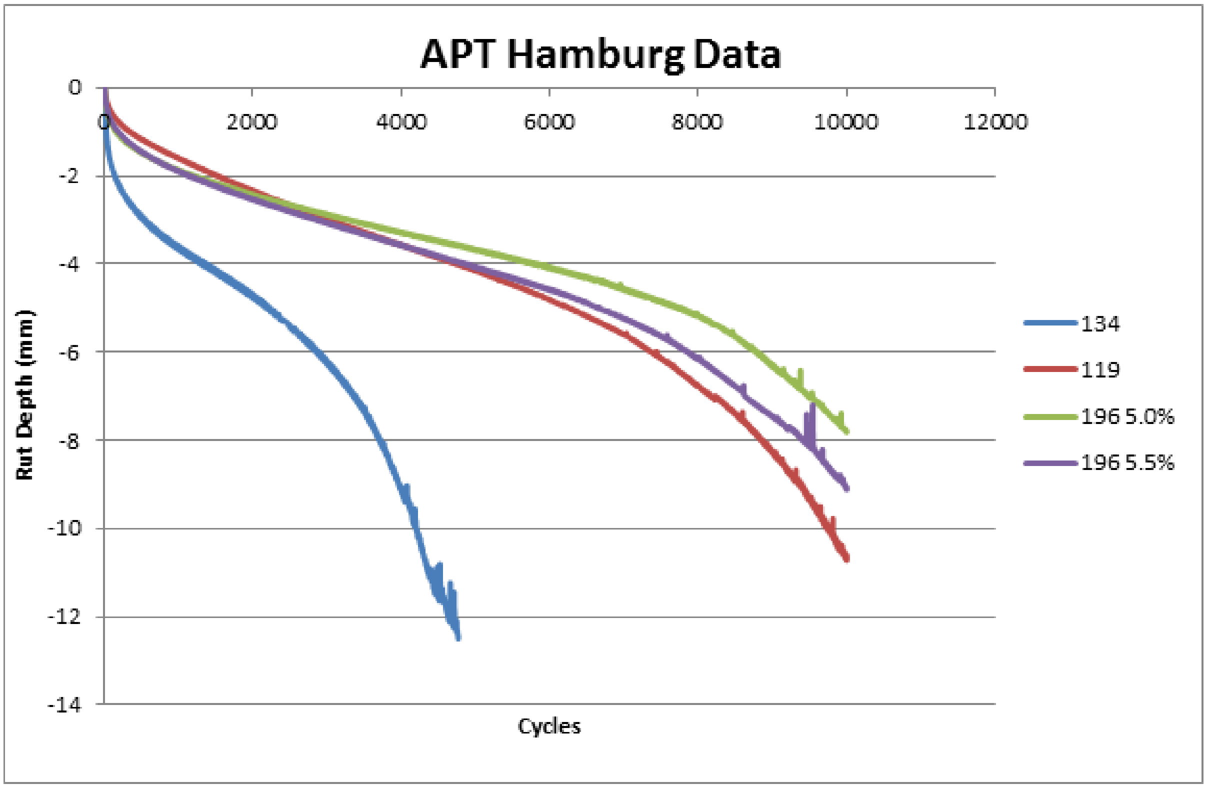

Figure 4.3. Hamburg Results for All Four Mixes.

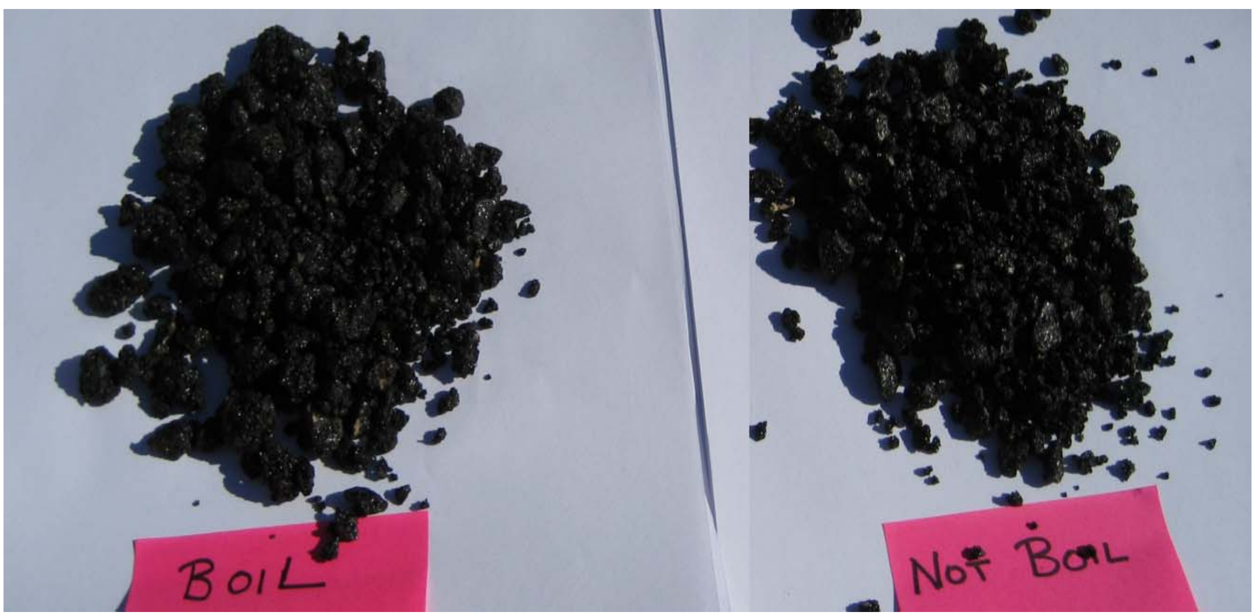

Figure 4.4. Boil Test Results on the Control Mix.

4.2 DISCUSSION OF RESULTS

With reference to Table 4.2, the ABR mix designs are in the light text and the TTI results are in bold text. These results were presented to the PMC. The following conclusions can be drawn based on the data in Table 4.2:

- The control mix did not pass the Hamburg; it failed in 4766 cycles and the mix stripped badly. The cause of the failure was probably related to the use of a PG 64-22 binder and the non-effectiveness of the liquid antistrip agent. All of the Hamburg tests performed by TTI rutted more than those reported by ABR.
- The control mix did pass the boil test without a problem; there appears to be a conflict between the two test methods.
- If the intent is to have a control mix that passes the Hamburg, then modifications are needed, which could include (a) changing the liquid antistrip, (b) using lime rather than liquid antistrip, and (c) changing gradation (removing field sand, for example).
- The 19 percent RAP provided acceptable results, resulting in the HWTT rutting 0.42 inch (10.7 mm) and the Overlay Tester lasting 122 cycles. ABR reported 0.1 inch (2.7 mm) in the HWTT. The cause of this difference is not known.
- The high RAP and RAS mix provided acceptable results of 0.3 inch (7.8 mm) in the HWTT and 62 cycles in the Overlay Tester.
- The high RAP and RAS mix designed at the higher lab molded density (with 0.5 percent more asphalt) did not produce acceptable results. The Overlay Tester only improved from 62 to 72 cycles. This mix is currently being redesigned.
- In general, these mixes did not produce the spread of Overlay Tester results typically observed with other RAP/RAS mixes around Texas. The value of 62 for the 19 percent RAP and 3 percent RAS is significantly higher than that reported in other areas of Texas, where numbers less than 10 are often reported. The higher values for this mix are probably associated with (a) the soft binder 64-22, (b) reasonable binder content of 5 percent, and (c) very good quality aggregates.

4.3 FOLLOW-UP TESTING ON HIGH RAP/RAS MIX

Based on the action items discussed above, additional performance tests were conducted on the RAP/RAS mix being designed using the balanced mix design approach. Two alternative binders were used: a PG 64-28 and a PG 64-22 modified with 3 percent styrene-butadiene rubber (SBR) latex. The original results for this mix and the results from mixing at both the 5.0 percent and 5.5 percent binder contents are tabulated below (these being the 96.5 percent and 97.5 percent target lab molded densities in the TGC).

Based on these results, the best performing mix is the PG 64-28 binder at an OAC of 5.5 percent, which rutted at 0.25 inch (6.4 mm) in the Hamburg after 10,000 load passes and lasted 173 cycles in the Overlay Tester. The SBR latex modified mix did best in the HWTT, but it appears that the binder content would need to be increased slightly to get acceptable OT results.

Table 4.3. Performance Results for the High RAP/RAS Mixes with a PG 64-28 and SBR Latex Modified Binders.

Design	% Rock				RAP %	RAS %	TD %	OAC %	LAS %	HWTT @10K	OT
	BPD	BPMS	MCMS	FS							
Contractor PG 64-22	**48**	**29**	**-**	**5.6**	**15**	**3**	**97**	**5.1**	**1**	**5.4**	**-**
PG 64-22	**48**	**29**	**-**	**5.6**	**15**	**3**	**96.5**	**5.0**	**1**	**7.8**	**62**
PG 64-22	**48**	**29**	**-**	**5.6**	**15**	**3**	**97.5**	**5.5**	**1**	**9.1**	**78**
PG 64-28	**48**	**29**	**-**	**5.6**	**15**	**3**	**96.5**	**5.0**	**1**	**3.5**	**61**
PG 64-28	**48**	**29**	**-**	**5.6**	**15**	**3**	**97.5**	**5.5**	**1**	**6.4**	**173**
PG 64-22 3% Latex	**48**	**29**	**-**	**5.6**	**15**	**3**	**96.5**	**5.0**	**1**	**3.2**	**27**
PG 64-22 3% Latex	**48**	**29**	**-**	**5.6**	**15**	**3**	**97.5**	**5.5**	**1**	**4.4**	**55**

From the results produced so far, the three mixes shown in Table 4.4 appear to be the best candidates for use in the APT tests.

Table 4.4. Mix Designs to Be Considered for Inclusion in the APT Test.

Design	% Rock				RAP %	RAS %	TD %	OAC %	LAS %	HWTT @10K	OT
	BPD	**BPMS**	**MCMS**	**FS**							
D119 RAP only PG64-22	**46**	**29**	**-**	**6**	**19**	**-**	**96.5**	**4.8**	**1**	**10.7**	**122**
D196 RAP/RAS PG64-22	**48**	**29**	**-**	**5.6**	**15**	**3**	**96.5**	**5.0**	**1**	**7.8**	**62**
D196 RAP/RAS PG64-28 (BMD)	**48**	**29**	**-**	**5.6**	**15**	**3**	**97.5**	**5.5**	**1**	**6.4**	**173**

The one remaining issue is the failure of the control mix to pass the current TxDOT specification, which includes passing the Hamburg test. Although the control mix does pass the boil test, it has problems passing the Hamburg test, as shown in Figure 4.2.

However, in a progress meeting with the PMC, it was decided to use this mix design even though it failed in the Hamburg test because it did pass the design criteria used in the Fort Worth District.

CHAPTER 5. MONITORING OF HMA CONSTRUCTION

Construction of the experimental pavements at the APRF facility occurred in mid-February 2013. The schematic of the sections that were constructed is shown in Figure 5.1. Details of the mixes used are in Tables 5.1 and 5.2.

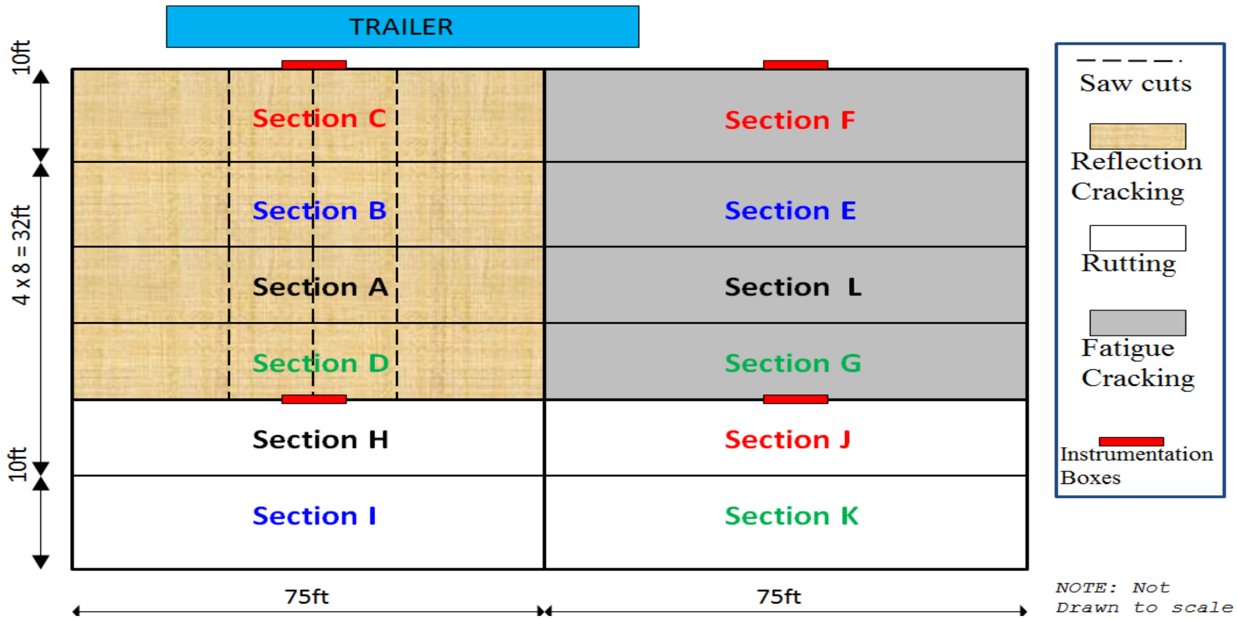

Figure 5.1. Test Sections Built at the APRF Facility.

Four asphalt surfacing mixes were used, and their design was described previously in Chapter 4. The control mix was placed as the final surface on Sections A, L, and H.

Table 5.1. Details of the Mixes Placed at the APRF Facility.

<table>
<tr><td rowspan="2">Test Section</td><td colspan="3">Reflection Cracking Experiment</td><td colspan="4">Fatigue Cracking Experiment</td></tr>
<tr><td>Surface 2.0 in.</td><td>Intermediate 2.0 in.</td><td>Base 8.0 in.</td><td>Test Section</td><td>Surface 2 in.</td><td>Base 8.0 in.</td><td>Subbase 8.0 in.</td></tr>
<tr><td>A</td><td>Type D</td><td rowspan="4">Type C</td><td rowspan="4">Cement (3.5%) Treated Base</td><td>L</td><td>Type D</td><td rowspan="4">Bridgeport Rock</td><td rowspan="4">Cement (2.0%) Treated Subbase</td></tr>
<tr><td>B</td><td>High RAP</td><td>E</td><td>High RAP</td></tr>
<tr><td>C</td><td>RAP&RAS</td><td>F</td><td>RAP&RAS</td></tr>
<tr><td>D</td><td>BMD</td><td>G</td><td>BMD</td></tr>
<tr><td colspan="4">Rutting Experiment</td><td colspan="4" rowspan="6">Type D contains no RAP
High RAP = (19% RAP)
RAP&RAS = (15%RAP + 3%RAS)
BMD = Balanced Mix Design
Type B and C mixes may or may not contain RAP</td></tr>
<tr><td>Test Section</td><td>Surface 2.0 in.</td><td>Intermediate 6.0 in.</td><td>Base 7.0 in.</td></tr>
<tr><td>H</td><td>Type D</td><td rowspan="4">Type B</td><td rowspan="4">Cement (3.5%) Treated Base</td></tr>
<tr><td>I</td><td>High RAP</td></tr>
<tr><td>J</td><td>RAP&RAS</td></tr>
<tr><td>K</td><td>BMD</td></tr>
</table>

Table 5.2. Initial Laboratory Design Information for the Mixes Used.

Mix	% Rock				RAP %	RAS %	TD %	OAC %	PG	LAS %	HWTT @10K	OT
	BPD	BPMS	MCMS	FS								
Type D Control												
D134 - TTI	**61**	**-**	**30**	**9**	**-**	**-**	**96.5**	**4.8**	**64-22**	**1**	**Failed @4,766**	**228**
High RAP												
D119 - TTI	**46**	**29**	**-**	**6**	**19**	**-**	**96.5**	**4.8**	**64-22**	**1**	**10.7**	**122**
RAP & RAS												
D196 -TTI +WMA	**48**	**29**	**-**	**5.6**	**15**	**3**	**96.5**	**5.0**	**64-22**	**1**	**7.8**	**62**
BMD												
D196 - TTI	**48**	**29**	**-**	**5.6**	**15**	**3**	**97.5**	**5.5**	**64-28**	**1**	**6.4**	**173**
Type C												
FT1C195	**50**	**27.6**		**5**	**15**	**2.4**	**97.0**	**4.7**	**64-22**	**1**		
Type B												
FT1B115	**38**	**32**			**30**		**97.0**	**4.1**	**64-22**	**1**		

One minor variation from the data above was the increase in the surface thickness from 2 to 3 inches (50 to 75 mm) for Sections L, E, F, and G. This increase was because these sections were heavily instrumented with strain gauges and other sensors. Hot mix was used to cover the sensors and their cables, and it was thought necessary to add additional thickness to the mat to prevent premature cracking of the final surface at these locations.

5.1 PHOTOS OF HMA PAVING

The base layers to the site were prepared by a contractor hired by UTA, and the HMA surfaces were placed by ABR with the HMA provided by their plant, which was less than 1 mile from the APRF. All construction proceeded smoothly, and the air temperature in the days of placement ranged from 50 to 70°F (10 to 21°C). Photos of the key steps in the construction sequence are shown in Figures 5.2 through 5.7.

Figure 5.2. Tack Coat Application on Section H prior to Placement of the Final Lift (CSS—1H @ 0.05 gal/sq yd).

Figure 5.3. Shuttle Buggy Used on All HMA Placement to Ensure Thermal Uniformity.

Figure 5.4. Paver with the Pave-IR Bar Attached.

Figure 5.5. Breakdown Roller (a Combination of Vibratory and Static Passes Were Used).

Figure 5.6. Multiple Passes of the Pneumatic Roller.

Figure 5.7. Finishing Roller for Edges and to Give a Smooth Finish.

Both TTI and ABR personnel monitored the placement of the mat, taking multiple temperature and density readings. Extensive HMA samples were also taken for validation and research testing. Up to 15 cores were taken from the transition areas in each section for lab testing and for validation of the field density measurements.

The only defect noted in the placement process was the wearing of the tack coat in the wheel paths with the passage of the shuttle buggy. This is a common occurrence in Texas and a cause for concern. However, over 70 cores were pulled from these sections, and not a single core delaminated.

One other issue was confusion about the required binder content for the BMD; the initial loads that were used for a parking space were made with 5.0 percent binder, not the required 5.5 percent. ABR plant personnel were notified and changes were made.

5.2 DATA COLLECTED DURING HMA PLACEMENT

Temperature at Time of Placement

Substantial efforts were made to ensure the uniformity of the HMA; extensive density and temperature measurements were made. Normally, the use of the Roadtec shuttle buggy ensures thermal uniformity, and this was found to be the case in all of the measurements made. Table 5.3 shows the temperatures recorded manually. The HMA temperature is a measurement of the mix while in the lay down machine. The surface temperature is that measured in the center of the mat about 5 ft behind the paver.

Table 5.3. Manual Measurements of Temperatures on the Test Section.

	Section C,F,J									
									Built	2/13/2013
	T1	T2	T3	T4	T5	AVG	Std Dev	COV	Type	RAP and RAS w/ Warm Mix
HMA Mix Temp	242	251	247	243	245	245.6	3.20	1.30		
Pvmnt Surface Temp	220	230	235	240	235	232	6.78	2.92		
	Section E,B,I									
	T1	T2	T3	T4	T5	AVG	Std Dev	COV	Built	2/13/2013
HMA Mix Temp	298	300	300	294	295	297.4	2.50	0.84	Type	High RAP
Pvmnt Surface Temp	288	289	285	288	295	289	3.29	1.14		
	Section K,D,G								Built	2/14/2013
	T1	T2	T3	T4	T5	AVG	Std Dev	COV	Type	MD 5.5% AC
HMA Mix Temp	292	290	291	286	282	288.2	3.71	1.29		
Pvmnt Surface Temp	283	279	281	277	275	279	2.83	1.01		
	Section A,H,L								Built	2/14/2013
	T1	T2	T3	T4	T5	AVG	Std Dev	COV	Type D	
HMA Mix Temp	282	293	291	295	292	290.6	4.50	1.55		
Pvmnt Surface Temp	286	280	278	273	276	278.6	4.36	1.57		

The lower placement temperatures for Sections C, F, and J were due to the use of the Evotherm WMA additive used in the HMA. This uniformity was confirmed with the Pave-IR data shown in Figures 5.8 through 5.11.

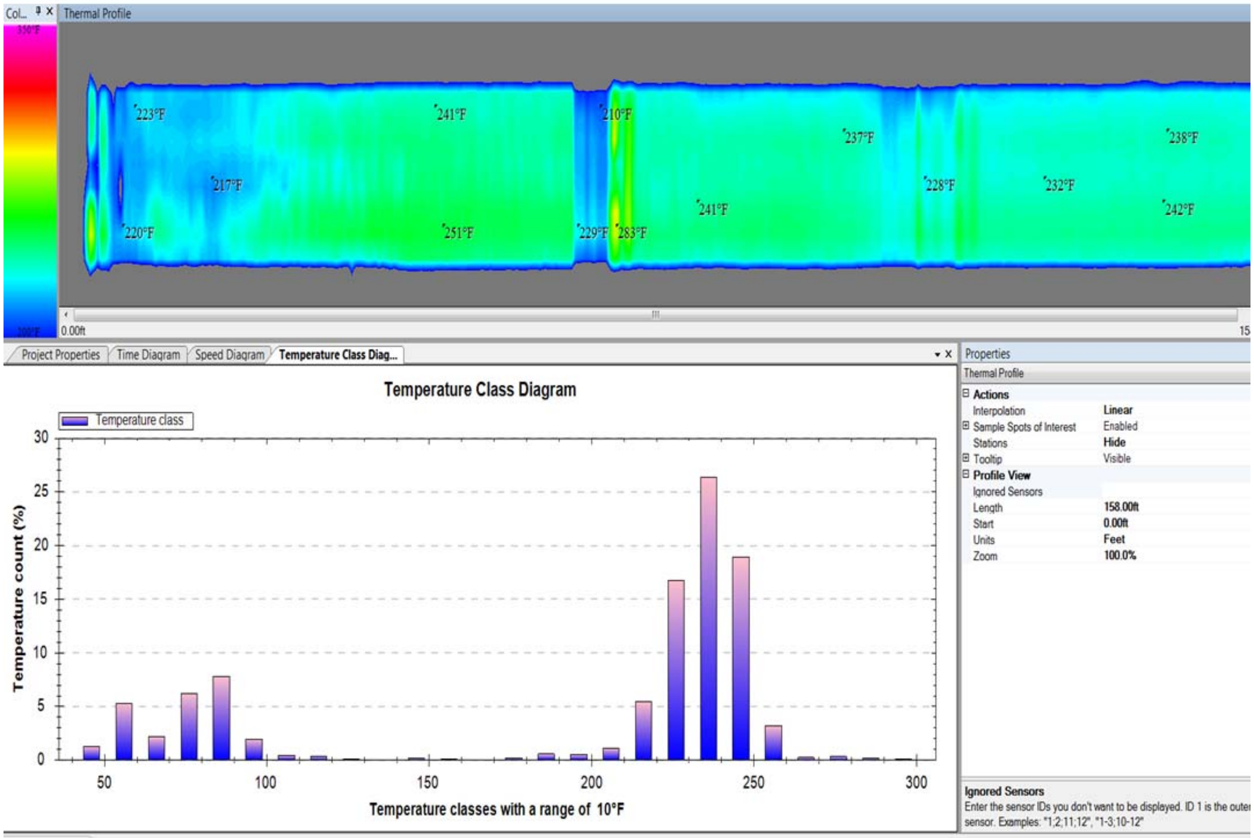

Figure 5.8. Pave-IR Output for Sections F and C (RAP/RAS + WMA).

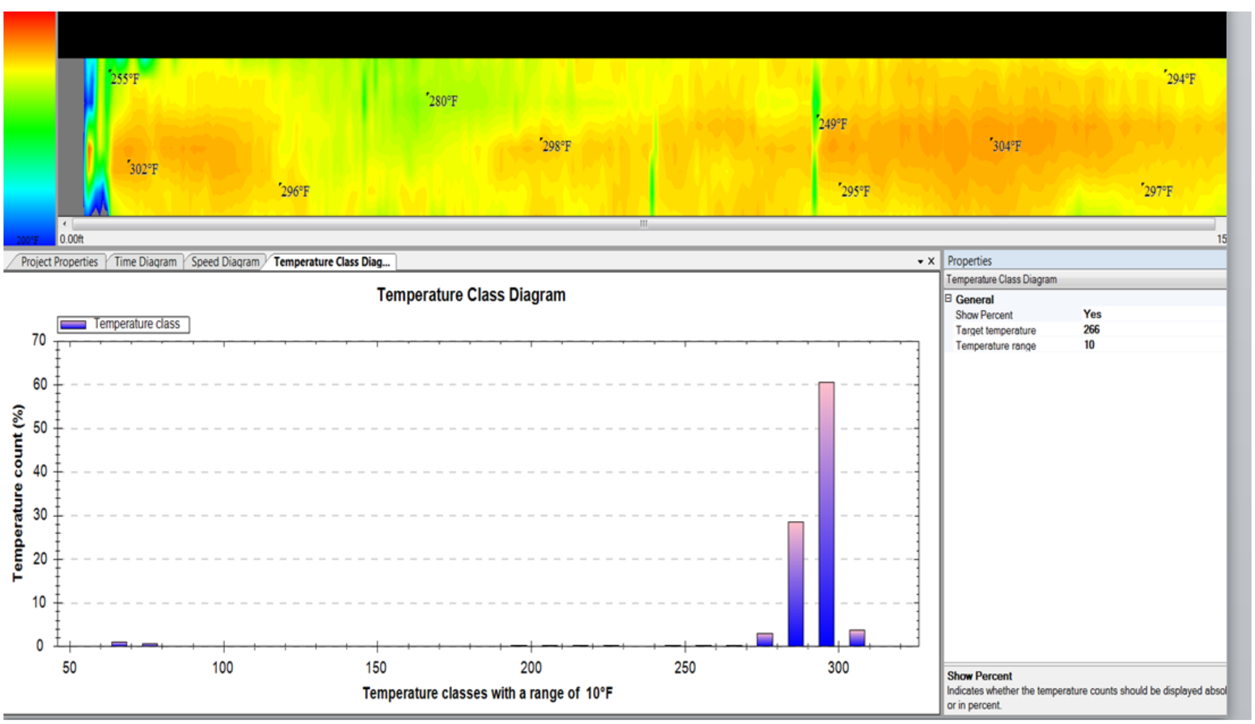

Figure 5.9. Pave-IR Output for Sections E and B (High RAP).

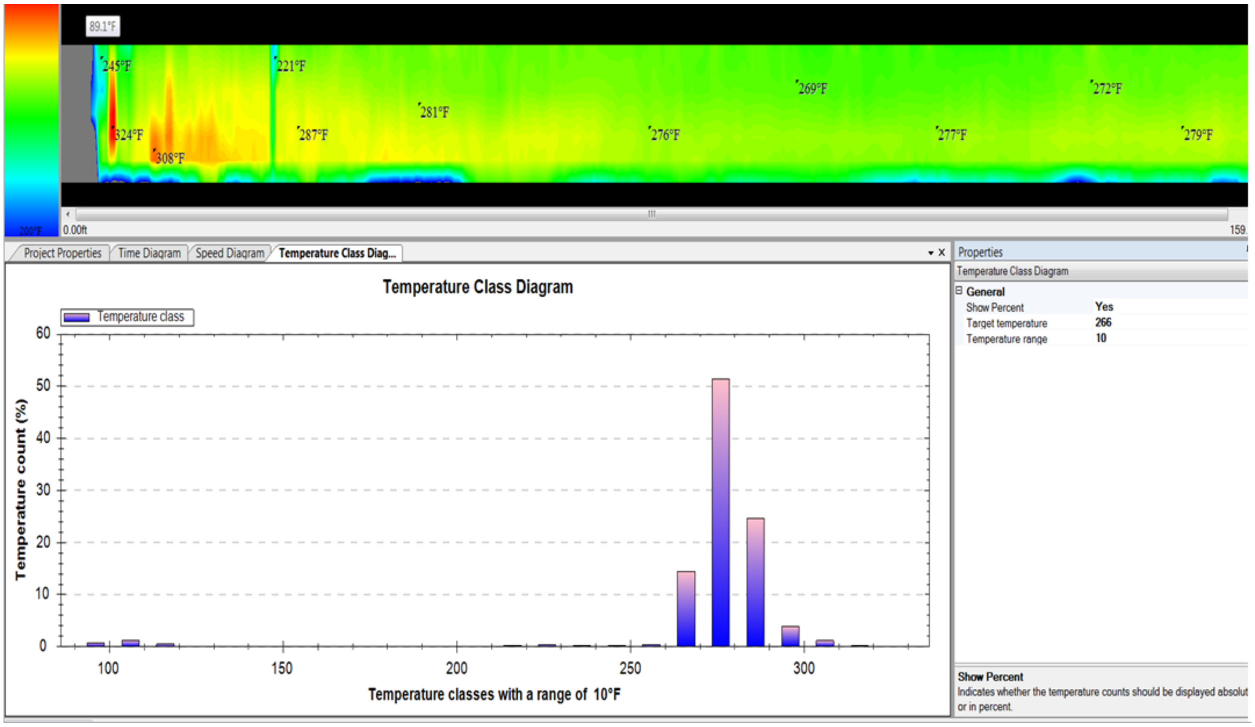

Figure 5.10. Pave-IR Output for Sections L and A (Control Mix).

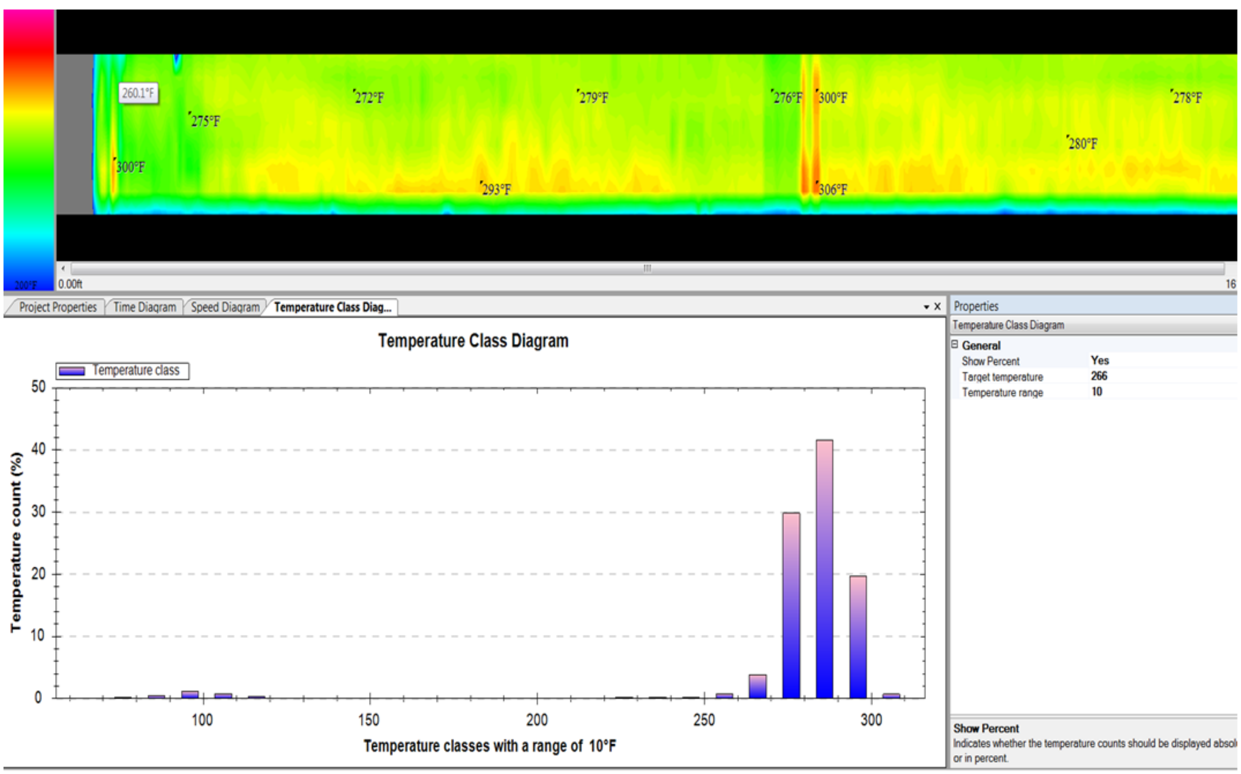

Figure 5.11. Pave-IR Output for Sections G and D (BMD).

In general, the Pave-IR data look good. The only concern would be the cold spots at the beginning of the WMA shown in Figure 5.8, where spots less than 220 were found. However, the

Evotherm WMA is designed to provide uniform compaction at lower temperatures. Figure 5.10 also shows a hot spot and a cold area for the control mix. In both cases, it was proposed to do a 100 percent area scan with a GPR to determine if these cold spots produce areas of low density. The control mix used a PG 64-22 binder with no RAP, and these mixes are generally thought to be more forgiving than mixes made with polymer modified binders such as the SBR latex. If the GPR detected concerns, then additional density measurements were made on the sections.

5.3 LABORATORY RESULTS ON FIELD CORES

Ten 5-gallon buckets of mix were taken from each mix design used and returned to the laboratory for project-related lab testing. Some of the samples, in the process of being taken, are shown in Figure 5.12. These were tested through routine and advanced characterization tests at TTI's lab. Additional samples were also pulled to support two additional TxDOT studies on RAP/RAS aging and HMA shearing. The coring operation is shown in Figure 5.13. All cores were taken well away from where the APT tests are or will be run; they were close to the transition between the sections.

Figure 5.12. Extensive Mix Sampling for the Lab Test Program.

Figure 5.13. Section Coring Close to the Transition Zone between Sections.

The complete set of field verification tests run by a certified HMA technician from ABR is shown in Appendix A. ABR has extensive experience with these mixes, and technicians defined the compaction sequence to ensure acceptable densities. For each mix, two static passes were made followed by two vibratory for the steel wheel breakdown roller. Multiple passes up to 20 passes were made with the pneumatic roller on each section. In all cases, field measurements with a non-nuclear density gauge found consistent air voids between 5 and 8.5 percent for the surface mixes. Cores were taken to verify these numbers.

ABR labs also performed the standard TxDOT QC/QA tests on the mixes to ensure that they were within gradation and binder content tolerances. The results of these tests are shown in Appendix B. All gradations were within specification tolerance.

Table 5.4 shows some of the basic results from the binder content measurements. These are measurements made on lab materials sampled during production. The two areas of concern are:

- The control mix was designed in the lab to require an asphalt content of 4.8 percent; however, in production the materials placed on the test section had an asphalt content of 5.3 percent.
- The balanced mix design was designed to have an asphalt content of 5.5 percent; however, in production the mix placed in the field had an asphalt content of only 5.2 percent.

Table 5.4. Comparison of Design and Trial Batch Binder Contents.

Mix	**Binder % Design**	**Binder % Field**	**Average % Air Voids (cores)**	**Lab molded density (plant mix)**
Type D (134)	4.8	5.3	7.3	97.4
RAP (119)	4.8	4.8	7.8	97.1
WMA (196)	5.0	4.9	8.1	96.9
BMD (196)	5.5	5.2	6.4	97.8

Samples of the mixes were also returned to TTI for additional Hamburg and Overlay verification tests to compare the as-placed mixes with the as-designed mixes. The results from the Hamburg test are shown in Table 5.5.

Table 5.5. Hamburg Results (mm of Rut Depth) on All Mixes.

Passes	**RAP (119)**	**Control**	**WM**	**BMD**
5,000	**3.35**	**9.85**	**3.09**	**4.07**
10,000	**8.92**	**12.84**	**9.12**	**6.73**
15,000	**12.8**		**13.67**	**12.57**
Failure	**11800**	**5950**	**11500**	**15450**

Table 5.6 shows a comparison of the lab and plant mix Hamburg results. These results are very comparable in that the control mix performed worse in the Hamburg, failing badly in both tests by stripping. The water in the test machine became cloudy, and the sample disintegrated badly.

This phenomena was discussed in the Task 5 lab design report. Also, as found in the lab, the balance mix design had the best performance in the Hamburg test.

Table 5.6. Comparison of Lab Design Results and Plant Mix Hamburg Results after 10,000 Passes.

	RAP (119)	Control (134)	WMA (196)	BMD (196)
Lab Design	**10.7**	**Failure @ 4766**	**7.8**	**6.4**
Plant Mix	**8.9**	**Failure @ 5960**	**9.1**	**6.7**

Verification testing of the samples in the Overlay Tester is still underway at the time of preparing this report. Preliminary tests have been completed on the field cores taken for the project, and these results are shown in Table 5.7. The OT results for the four mixes follow the same trend as those obtained in design, with the control and the BMD mixes best at 383 and 442 cycles each and the high RAP and RAP/RAS/WMA significantly worse at 108 and 175 cycles. It is interesting to note that these values are significantly higher than those obtained in the laboratory phase (228, 122, 62, and 173). However, it must be recalled that the laboratory mixes without WMA were aged for 2 hours before molding, and as per TxDOT requirements, the WMA samples were aged for 4 hours.

Table 5.7. Lab Results from the Field Cores.

Field core time	Section	Mix type	Hamburg (mm)					Mr (ksi)	OT		IDT (psi)
			5000	10000	15000	20000	failure		max load (lbs)	OT cycles	
Just after construction, Feb. 13, 2013	A	Virgin D PG64-22	15.1				4600	416.7	523.7	383	120.9
	B	High RAP D PG64-22	6.0	12.0	14.0		11216	478.1	652.3	108	117.75
	C	RAP/RAS D PG64-22 Evotherm	13.4	15.3			5350	385.7	611.4	175	106.7
	D	BMD-RAP/RAS D PG64-28	4.5	13.0	15.1		11400	354.7	694.4	442	121.1
	A-bottom Type C	RAP C PG64-22	12.9	15.1			5800	454.9	643.1	97	109.7
	B-bottom Type C	RAP C PG64-22	7.7	14.3	15.1		10450	550.5	683.9	67	129.4
	C-bottom Type C	RAP C PG64-22	5.7	9.9	9.5			477.7	780.2	56	116.7
	D-bottom Type C	RAP C PG64-22	9.0	15.2			9750	432.1	545.4	36	85.4
	Ty B		4.5	14.9				599.3	715.1	60	121.7

APPENDIX A. ABR FIELD DENSITY LOGS

Austin Bridge and Road
1B Inspection Sheet

Project Name / Number	**APT RESEARCH**	**Date:**	**2/11/2013**

Hot Mix Supplier	FTW
Ambient Temp. Range/Weather	5O-55 Cloudy
Mix Type / Lot & SL	FT1C195
Rice Gravity	2.477
Range of Densities	92-95
Range of LBS/CU FT.	142-145
HMAC Temperature Range	290-270
Spec Number:	
Paving Foreman	GEORGE ARRENDONDO
Rolling Pattern:	
Breakdown	1 static & 3 vibratory
* **Operator**	LUPE ZUNIGA
Intermediate	15 Pneumatic
* **Operator**	FELX SALAS
Finish	2 static
* **Operator**	LUPE ZUNIGA
Technician:	A.WELLS

Figure A.1. Type C Base Mix.

Austin Bridge and Road
1B Inspection Sheet

Project Name / Number	**TEST STRIP**	**Date:**	**2/11/2013**

Hot Mix Supplier	FTW
Ambient Temp. Range/Weather	50-58 Cloudy
Mix Type / Lot & SL	FT1B115 /
Rice Gravity	2.500
Range of Densities	91-93
Range of LBS/CU FT.	141.5-145
HMAC Temperature Range	295-261
Spec Number:	341-022
Paving Foreman	GOERGE ARRENDONDO
Rolling Pattern:	
Breakdown	3static & 1 vibratory
* **Operator**	LOUPE ZUNIGA
Intermediate	15 Pneumatic
* **Operator**	FELX SALAS
Finish	2 static
* **Operator**	LOUPE ZUNIGA
Technician:	A.WELLS

Figure A.2. Type B Base Mix.

Austin Bridge and Road
1B Inspection Sheet

Project Name / Number	**APT RESEARCH**	**Date:**	**2/14/2013**

Hot Mix Supplier	FTW
Ambient Temp. Range/Weather	5O-65 SUNNY
Mix Type / Lot & SL	FT1D134
Rice Gravity	2.484
Range of Densities	91.5-94
Range of LBS/CU FT.	141.5-144.5
HMAC Temperature Range	320-270
Spec Number:	
Paving Foreman	GEORGE ARRENDONDO
Rolling Pattern:	
Breakdown	2 static & 2 vibratory
*** Operator**	LUPE ZUNIGA
Intermediate	20 Pneumatic
*** Operator**	FELX SALAS
Finish	1 static
*** Operator**	LUPE ZUNIGA
Technician:	A.WELLS

Figure A.3. Control Mix.

Austin Bridge and Road
1B Inspection Sheet

Project Name / Number	**APT RESEARCH**	**Date:**	**2/11/2013**

Hot Mix Supplier	FTW
Ambient Temp. Range/Weather	5O-65 SUNNY
Mix Type / Lot & SL	FT1D119
Rice Gravity	2.484
Range of Densities	91.5-94
Range of LBS/CU FT.	141.5-144.5
HMAC Temperature Range	320-270
Spec Number:	
Paving Foreman	GEORGE ARRENDONDO
Rolling Pattern:	
Breakdown	2 static & 2 vibratory
*** Operator**	LUPE ZUNIGA
Intermediate	20 Pneumatic
*** Operator**	FELX SALAS
Finish	1 static
*** Operator**	LUPE ZUNIGA
Technician:	A.WELLS

Figure A.4. High RAP Mix.

Austin Bridge and Road
1B Inspection Sheet

Project Name / Number	**APT RESEARCH**	**Date:**	**2/13/2013**

Hot Mix Supplier	FTW
Ambient Temp. Range/Weather	50-65 SUNNY
Mix Type / Lot & SL	FT1D196 WMA
Rice Gravity	2.474
Range of Densities	91.5-94.5
Range of LBS/CU FT.	141.4-144.7
HMAC Temperature Range	255-230

Spec Number:	
Paving Foreman	GEORGE ARRENDONDO
Rolling Pattern:	
Breakdown	2 static & 2 vibratory
*** Operator**	LUPE ZUNIGA
Intermediate	20 Pneumatic
*** Operator**	FELX SALAS
Finish	2 static
*** Operator**	LUPE ZUNIGA
Technician:	A.WELLS

Figure A.5. RAP/RAS WMA Mix.

Austin Bridge and Road
1B Inspection Sheet

Project Name / Number	**APT RESEARCH**	**Date:**	**2/14/2013**

Hot Mix Supplier	FTW
Ambient Temp. Range/Weather	50-65 SUNNY
Mix Type / Lot & SL	FT1D196 BMD
Rice Gravity	2.461
Range of Densities	91.5-94.0
Range of LBS/CU FT.	141.5-144.6
HMAC Temperature Range	320-270

Spec Number:	
Paving Foreman	GEORGE ARRENDONDO
Rolling Pattern:	
Breakdown	2 static & 2 vibratory
*** Operator**	LUPE ZUNIGA
Intermediate	20 Pneumatic
*** Operator**	FELX SALAS
Finish	1 static
*** Operator**	LUPE ZUNIGA
Technician:	A.WELLS

Figure A.6. Balance Mix Design.

APPENDIX B. ABR MIX QUALITY ASSURANCE TESTING

TEXAS DEPARTMENT OF TRANSPORTATION

QC/QA TEST DATA : CONTRACTOR SUBLOT 1

SAMPLE ID:	FT1C195	DATE LOT OPENED:	2/11/13
LOT NUMBER:		LETTING DATE:	
SAMPLE STATUS:		CONTROLLING CSJ:	
COUNTY:	Tarrant	SPEC YEAR:	2004
SAMPLED BY:	Danny / DJ Meek	SPEC ITEM:	
SAMPLE LOCATION:		SPECIAL PROVISION:	341-_024
MATERIAL CODE:		MIX TYPE:	ITEM341_C_Coarse_Surface
MATERIAL NAME:	Ty C (64-22) RAP and RAS		
PRODUCER:			
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:	Surface	STATION:		DIST. FROM CL:	
Sublot Sample Date:	2/11/13	**Sublot Location, (Tons)**		**Production Location, (Tons)**	

DETERMINATION OF ASPHALT CONTENT Ignition Oven Method: Tex-236-F		
AC % from Ignition Oven Method/Corrected:	**4.9**	**4.9**
Ratio of Recycled to Total Binder, %	10.2	

DETERMINATION OF RICE SPECIFIC GRAVITY-Tex-227-F	Laboratory
(A) Weight of Dry Sample in Air:	1473.4
(D) Weight of Calibrated Pyc. w/H2O:	1393.5
(E) Weight of Sample, Pyc. and H2O:	2272.0
A/(D+A-E) Rice Specific Gravity (G_r)	2.477
(Asd) Weight of Surface Dry Sample in Air:	

GRADATION OF EXTRACTED AGGREGATE-Tex-200-F

GRADATION SAMPLE FROM IGNITION OVEN: Tex-236-F

Ignited Sample Original Dry Weight: 1827.9 — Dry Weight After Washing:

Sieve Size:	Individual Weight Retained (g) Individual	Cumulative Weight Retained (g)	*Individual Percent Retained*	*Cumulative Percent Retained*	*Cumulative Percent Passing*	JMF Individual Retained Limits, %	In Tolerance	*Reference Zone*
3/4"	0.0	0.0	**0.0**	0.0	100.0	0-5	☑	
3/8"	312.0	312.0	**17.1**	17.1	82.9	13.9-23.9	☑	
No. 4	440.8	752.8	**24.1**	41.2	58.8	18.8-28.8	☑	
No. 8	409.9	1,162.7	**22.4**	63.6	36.4	11.8-21.8	☒	
No. 30	316.5	1,479.2	**17.3**	80.9	19.1	14-20	☑	
No. 50	91.9	1,571.1	**5.1**	86.0	14.0	4.9-10.9	☑	
No. 200	187.1	1,758.2	**10.2**	96.2	3.8	9.4-15.4	☑	
-No. 200	69.7	*Not adjusted for ignition oven correlation*						
	0.0	Sieving Loss (g)						
Total -No. 200	69.7	1,827.9	**3.8**	100.0	0.0	2.0-5.2	☑	
Total Weight:	1,827.9							
	0.0	Sieving Loss (g), from 'original dry sample'						

EFFECT OF WATER ON BITUMINOUS -Tex-530-C	
Estimated Percent of Stripping, %:	

THERMAL PROFILE - Tex-244-F	
Thermal Segregation	
MAT SEGREGATION - Tex-207-F, Part V	
Segregation Density Profile	
JOINT DENSITY - Tex-207-F, Part VII	
Longitudinal Joint Density	
DRAIN-DOWN - Tex-235-F	
Drain-down, %:	

FILM THICKNESS

Figure B.1. Type C Base Mix.

TEST DATA

SAMPLE ID:	FT1B115	DATE LOT OPENED:	2/11/13
LOT NUMBER:		LETTING DATE:	
SAMPLE STATUS:		CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	2004
SAMPLED BY:	Danny / DJ Meek	SPEC ITEM:	
SAMPLE LOCATION:	Plant	SPECIAL PROVISION:	
MATERIAL CODE:		MIX TYPE:	Type__B
MATERIAL NAME:	Ty B 30% (-1/2") Fractionated RAP		
PRODUCER:	Austin Asphalt		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:	Base	STATION:		DIST. FROM CL:	

DETERMINATION OF ASPHALT CONTENT Ignition Oven Method: Tex-236-F

Asphalt Content from Ignition Method/Corrected, (%):	4.2	4.2

ETERMINATION OF RICE SPECIFIC GRAVITY-Tex-227-

	Laboratory	Roadway
(A) Weight of Dry Sample in Air:	1459.6	1484.3
(D) Weight of Calibrated Pyc. w/H2O:	1393.5	1393.5
(E) Weight of Sample, Pyc. and H2O:	2266.6	2282.9
A/(D+A-E) Rice Specific Gravity (Gr):	2.489	2.495
(Asd) Weight of Surface Dry Sample in Air:		

EFFECT OF WATER ON BITUMINOUS -Tex-530-C

Estimated Percent of Stripping:	

Determination of Moisture Tex-212-F :

GRADATION OF EXTRACTED AGGREGATE-Tex-229-F

GRADATION SAMPLE FROM IGNITION OVEN

ited Sample Original Dry Weight:	2174.4	Dry Weight After Washing:	

Sieve Size:	Individual Weight Retained (g)	Cumulative Weight Retained (g)	Individual Percent Retained	Cumulative Percent Retained	Cumulative Percent Passing	JMF Individual Retained Limits, %	In Tolerance	Restricted Zone
1"	0.0	0.0	**0.0**	0.0	100.0	0.0-5.0	☑	
3/4"	128.4	128.4	**5.9**	5.9	94.1	0.0-7.9	☑	
3/8"	317.0	445.4	**14.6**	20.5	79.5	13.0-23.0	☑	
No. 4	436.4	881.8	**20.1**	40.6	59.4	14.9-24.9	☑	
No. 8	469.3	1,351.1	**21.5**	62.1	37.9	12.3-22.3	☑	
No. 30	430.0	1,781.1	**19.8**	81.9	18.1	16.8-22.8	☑	
No. 50	129.3	1,910.4	**6.0**	87.9	12.1	5.1-11.1	☑	
No. 200	177.9	2,088.3	**8.1**	96.0	4.0	7.5-13.5	☑	
-No. 200	86.1							
	0.0	Loss (g)						
Total -No. 200	86.1	2,174.4	**4.0**	100.0	0.0	2.0-5.5	☑	
Total Weight:	2,174.4							
	0.0	Sieving Loss (g), from 'original dry sample'						

termination of Hydrocarbon-Volatile Content: Tex-213

Still Number:	
Still Weight (g):	
Weight of Still and Sample (g):	
Sample Weight (g):	
Top Meniscus Reading (mL):	
Bottom Meniscus Reading (mL):	
Volume of Volatiles (mL):	
Specific Gravity of Volatiles:	
Percent Hydrocarbon Volatiles (%):	

Figure B.2. Type B Base Mix.

TEST DATA

SAMPLE ID:	JMF 4	DATE LOT OPENED:	2/14/13
LOT NUMBER:		LETTING DATE:	
SAMPLE STATUS:	Sample @ 42 Tons	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	2004
SAMPLED BY:	Danny Meek	SPEC ITEM:	
SAMPLE LOCATION:	Plant	SPECIAL PROVISION:	
MATERIAL CODE:		MIX TYPE:	Type__D
MATERIAL NAME:	Ty D		
PRODUCER:	Austin Asphalt		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:	Surface	STATION:		DIST. FROM CL:	

DETERMINATION OF ASPHALT CONTENT Ignition Oven Method: Tex-236-F		
Asphalt Content from Ignition Method/Corrected, (%):	5.3	5.3

DETERMINATION OF RICE SPECIFIC GRAVITY-Tex-227-F	Laboratory
(A) Weight of Dry Sample in Air:	1439.3
(D) Weight of Calibrated Pyc. w/H2O:	1392.9
(E) Weight of Sample, Pyc. and H2O:	2254.2
A/(D+A-E) Rice Specific Gravity (Gr):	2.490
(Asd) Weight of Surface Dry Sample in Air:	

EFFECT OF WATER ON BITUMINOUS -Tex-530-C	
Estimated Percent of Stripping:	

Determination of Moisture Tex-212-F :	

GRADATION OF EXTRACTED AGGREGATE-Tex-229-F

GRADATION SAMPLE FROM IGNITION OVEN

ited Sample Original Dry Weight:	1932.6	Dry Weight After Washing:	

Sieve Size:	Individual Weight Retained (g)	Cumulative Weight Retained (g)	Individual Percent Retained	Cumulative Percent Retained	Cumulative Percent Passing	JMF Individual Retained Limits, %	In Tolerance	Restricted Zone
1/2"	0.0	0.0	**0.0**	0.0	100.0	0.0-5.0	☑	
3/8"	16.2	16.2	**0.8**	0.8	99.2	0.0-6.5	☑	
No. 4	524.9	541.1	**27.2**	28.0	72.0	26.7-36.7	☑	
No. 8	548.3	1,089.4	**28.4**	56.4	43.6	21.1-31.1	☑	
No. 30	358.3	1,447.7	**18.5**	74.9	25.1	13.3-19.3	☑	
No. 50	91.0	1,538.7	**4.7**	79.6	20.4	2.8-8.8	☑	
No. 200	300.1	1,838.8	**15.5**	95.1	4.9	11.9-17.9	☑	
-No. 200	92.8							

Determination of Hydrocarbon-Volatile Content: Tex-213-F	
Still Number:	
Still Weight (g):	
Weight of Still and Sample (g):	
Sample Weight (g):	
Top Meniscus Reading (mL):	
Bottom Meniscus Reading (mL):	
Volume of Volatiles (mL):	
Specific Gravity of Volatiles:	
Percent Hydrocarbon Volatiles (%):	

Figure B.3. Control Mix (No RAP/RAS).

HMAC MIX PROPERTIES

Refresh Workbook

File Version: 08/14/08 11:17:27

SAMPLE ID:	JMF 4	SAMPLED DATE:	2/13/13
TEST NUMBER:	FT1D119	LETTING DATE:	
SAMPLE STATUS:	Pulled @ 45 Tons	CONTROLLING CSJ:	
COUNTY:	Dallas	SPEC YEAR:	2004
SAMPLED BY:	Danny / DJ Meek	SPEC ITEM:	ITEM341_D_Fine_Surface
SAMPLE LOCATION:	FTW Plant	SPECIAL PROVISION:	
MATERIAL CODE:		MIX TYPE:	Type__D
MATERIAL NAME:	Ty D 20% (-1/2") Fractionated RAP		
PRODUCER:	Austin Asphalt (AN AUSTIN INDUSTRIES COMPANY)		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:	Surface	STATION:		DIST. FROM CL:	

PRODUCTION DATA

Quantity actually placed, Tons	

DETERMINATION OF ASPHALT CONTENT

Determination of asphalt content *by:*	**Ignition Oven Method**	**PG Binder:**	64-22
Original Mix Design Asphalt Content, %:	4.8	Current JMF Asphalt Content, %:	4.8
Ignition Correction Factor	0 %		

COMBINED AGGREGATE GRADATION:Tex-229-F

Method used to obtain aggregate: **Ignition Oven Method**

Sieve Size:	Size (mm)	Master Specification % Passing Tolerances	*Master Specification % Passing Restricted*	**Design JMF Cumulative Percent Passing**	In Tolerance	*Restricted Zone*	Current JMF Design % Passing Tolerances	**Current JMF Cumulative Percent Passing**	In Tolerance	*Restricted Zone*	Sieve Size:	TxDOT Ignition Oven Correction Factor,%:
1/2"	12.500	98-100		100.0	☑		98-100	100.0	☑		1/2"	
3/8"	9.500	85-100		98.9	☑		93.9-100	96.8	☑		3/8"	
No. 4	4.750	50-70		66.1	☑		59-69	66.1	☑		No. 4	
No. 8	2.360	35-46		43.5	☑		38.5-46	38.9	☑		No. 8	
No. 30	0.600	15-29		25.4	☑		17.8-23.8	19.5	☑		No. 30	
No. 50	0.300	7-20		16.1	☑		7.2-13.2	13.2	☑		No. 50	
No. 200	0.075	2-7		3.1	☑		2-3.2	3.1	☑		No. 200	

DETERMINING DENSITY & PROPERTIES OF BITUMINOUS MIXTURES

Press correlation factor used?	No	Ge (Effective) specific gravity:	2.685	% Mineral Filler (by wt. of dry aggregate)	
Press correlation factor:		**G1 (specific gravity of asphalt):**	1.001		
TxDOT press ID & serial no.:		Theoretical max.specific gravity:	2.483	Wet Track Abrasion Wear Value (g/sq. ft.)	
Contractor press ID no.:		Mix design target density:	96.5		

Figure B.4. High RAP Mixes.

TEXAS DEPARTMENT OF TRANSPORTATION

HMAC MIX PROPERTIES

Refresh Workbook

File Version: 06/09/08 14:31:42

SAMPLE ID:	JMF 4	SAMPLED DATE:	2-13-13
TEST NUMBER:		LETTING DATE:	
SAMPLE STATUS:	**Pulled at 42 Tons**	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	2004
SAMPLED BY:	Danny / DJ Meek	SPEC ITEM:	
SAMPLE LOCATION:	Ft. Worth Plant	SPECIAL PROVISION:	
MATERIAL CODE:		MIX TYPE:	Type__D
MATERIAL NAME:	Ty D 15% (-1/2") Fractionated RAP and 3% RAS		
PRODUCER:	Austin Asphalt		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:	Surface	STATION:		DIST. FROM CL:	

PRODUCTION DATA

Quantity actually placed, Tons:

DETERMINATION OF ASPHALT CONTENT

Determination of asphalt content *by*: **Ignition Oven Method** — **PG Binder:** 64-22

Original Mix Design Asphalt Content, %: 4.9 — Current JMF Asphalt Content, %: 4.9 — Ignition Correction Factor: %

COMBINED AGGREGATE GRADATION:Tex-229-F

Method used to obtain aggregate: **Ignition Oven Method**

Sieve Size:	Size (mm)	Master Specification % Passing Tolerances	*Master Specification % Passing Restricted*	**Design JMF Cumulative Percent Passing**	In Tolerance	*Restricted Zone*	Current JMF Design % Passing Tolerances	**Current JMF Cumulative Percent Passing**	In Tolerance	*Restricted Zone*	Sieve Size:	TxDOT Ignition Oven Correction Factor,%:
1/2"	12.500	98-100		100.0	☑		98-100	100.0	☑		1/2"	
3/8"	9.500	85-100		99.1	☑		94.1-100	99.1	☑		3/8"	
No. 4	4.750	50-70		65.9	☑		60.9-70	65.9	☑		No. 4	
No. 8	2.360	35-46		43.5	☑		38.5-46	41.0	☑		No. 8	
No. 30	0.600	15-29		25.1	☑		19.6-25.6	24.1	☑		No. 30	
No. 50	0.300	7-20		15.9	☑		11.9-17.9	17.0	☑		No. 50	
No. 200	0.075	2-7		3.4	☑		2-7	4.6	☑		No. 200	

Figure B.5. RAP/RAS WMA Mix.

TEXAS DEPARTMENT OF TRANSPORTATION

TEST DATA

SAMPLE ID:	JMF 4	DATE LOT OPENED:	2-14-13
LOT NUMBER:		LETTING DATE:	
SAMPLE STATUS:	Pulled at 84 Tons	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	2004
SAMPLED BY:	Danny / DJ Meek	SPEC ITEM:	
SAMPLE LOCATION:	Ft. Worth Plant	SPECIAL PROVISION:	
MATERIAL CODE:		MIX TYPE:	Type__D
MATERIAL NAME:	Ty D (64-28) 15% (-1/2") Fractionated RAP and 3% RAS		
PRODUCER:	Austin Asphalt		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:	Surface	STATION:		DIST. FROM CL:	

DETERMINATION OF ASPHALT CONTENT Ignition Oven Method: Tex-236-F

Asphalt Content from Ignition Method/Corrected, (%):	5.2	5.2

ETERMINATION OF RICE SPECIFIC GRAVITY-Tex-227- Laboratory

(A) Weight of Dry Sample in Air:	1469.6
(D) Weight of Calibrated Pyc. w/H2O:	1392.9
(E) Weight of Sample, Pyc. and H2O:	2265.4
A/(D+A-E) Rice Specific Gravity (Gr):	2.461
(Asd) Weight of Surface Dry Sample in Air:	

EFFECT OF WATER ON BITUMINOUS - Tex-530-C

Estimated Percent of Stripping:	0

Determination of Moisture Tex-212-F :

GRADATION OF EXTRACTED AGGREGATE - Tex-229-F

GRADATION SAMPLE FROM IGNITION OVEN

ited Sample Original Dry Weight:	1918.1	Dry Weight After Washing:	

Sieve Size:	Individual Weight Retained (g)	Cumulative Weight Retained (g)	Individual Percent Retained	Cumulative Percent Retained	Cumulative Percent Passing	JMF Individual Retained Limits, %	In Tolerance	Restricted Zone
1/2"	0.0	0.0	**0.0**	0.0	100.0	0.0-5.0	☑	
3/8"	10.2	10.2	**0.5**	0.5	99.5	0.0-5.9	☑	
No. 4	549.0	559.2	**28.7**	29.2	70.8	28.2-38.2	☑	
No. 8	559.8	1,119.0	**29.1**	58.3	41.7	19.9-29.9	☑	
No. 30	358.7	1,477.7	**18.7**	77.0	23.0	13.9-19.9	☑	
No. 50	102.3	1,580.0	**5.4**	82.4	17.6	4.1-10.1	☑	
No. 200	243.5	1,823.5	**12.7**	95.1	4.9	9.4-15.4	☑	
-No. 200	94.6							
	0.0	Loss (g)						
Total -No. 200	94.6	1,918.1	**4.9**	100.0	0.0	2.6-6.6	☑	
Total Weight:	1,918.1							

termination of Hydrocarbon-Volatile Content: Tex-213

Still Number:	
Still Weight (g):	
Weight of Still and Sample (g):	
Sample Weight (g):	
Top Meniscus Reading (mL):	
Bottom Meniscus Reading (mL):	
Volume of Volatiles (mL):	
Specific Gravity of Volatiles:	
Percent Hydrocarbon Volatiles (%):	

Figure B.6. Balanced Mix Design.