AN ANALYSIS OF IMPACT FACTORS ON THE ILLINOIS FLEXIBILITY INDEX TEST

BY

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THESIS

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ABSTRACT

The use of recycled materials in asphalt pavements has become widespread in recent years. Materials such as recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS) have been incorporated into the material design of typical pavements. The use of these materials is both economically and environmentally friendly, at least initially. However, asphalt concrete materials with high recycled content have been shown to have some performance issues, leading to deterioration before the end of the design life. This early deterioration may negate any environmental or economic benefit initially obtained from the use of recycled materials.

The typical modes of failure for asphalt pavements with high recycled content are thermal cracking or early fatigue cracking. While RAP and RAS contribute a significant amount of recycled asphalt binder, that is asphalt binder replacement (ABR), the binder may be too stiff for the given application. For this reason, standard Superpave design may be insufficient to prevent cracking when ABR is present. As a result, the Illinois Center for Transportation has developed the Illinois Flexibility Index Test (I-FIT) to evaluate the cracking potential of an asphalt concrete mixture.

The I-FIT method is in its early stages, and various impact factors on the test's output need to be understood. While laboratory-produced specimens can be easily controlled, the qualities of field core specimens are typically out of the researcher's control. Two main parameters, while controlled for laboratory-produced specimens, will typically be uncontrolled for field core specimens. These parameters are the specimen thickness and

the air void content. It is vital to understand the effect of these parameters on the I-FIT method; therefore, these effects are a main focus of investigation in this thesis.

Another main focus of this thesis is the mitigation of asphalt concrete mixture stiffness. The I-FIT method was developed specifically to evaluate the flexibility of an asphalt concrete mix. It is ideal for identifying mixtures of excessive stiffness as a result of high levels of ABR. It is also ideal for evaluating the success of methods of stiffness mitigation, that is, increasing flexibility to reduce cracking potential. Typical methods of stiffness mitigation—for example, virgin binder softening—are evaluated in terms of the I-FIT method. Additionally, atypical methods of stiffness mitigation are evaluated, specifically mix-applied rejuvenation.

Mix-applied rejuvenation, which closely resembles hot-in-place recycling, is evaluated on a large scale. Rejuvenation of plant mix, laboratory-produced specimens, and field cores is evaluated, and the effectiveness of mix-applied rejuvenation is analyzed via the I-FIT method. Preferable methods of mix-applied rejuvenation are determined, and field applications are suggested.

This thesis provides an understanding of the effect of mix and test specimen geometry parameters on I-FIT results. Additionally, the effect of aging on I-FIT results is presented.

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1. Introduction

1.1. Background

Asphalt material surface failure can typically occur in one of two modes. At high temperatures, asphalt materials may permanently deform under loads, which is known as rutting. Widely accepted as a test of high temperature rutting failure is the Hamburg Wheel Tracking Test *(1)*. At low temperatures, materials might crack under thermal contraction. A proper test to evaluate cracking potential has not been settled on and is currently debatable.

Early attempts were made during the development of Superpave to quantify a mixture's thermal cracking resistance. The Strategic Highway Research Program (SHRP) recommended the indirect tensile creep and failure test at low temperatures (ITLT) to characterize thermal cracking behavior in asphalt mixes *(2)*.

Later on, evaluating fracture energy via the disk shaped compact tension, or DC(T) test *(3)*, began to dominate investigation into low temperature thermal cracking resistance. This test has been used extensively for various elastic materials in the literature, including steel. Extensive investigations at the University of Illinois evaluated various mix design parameters via DC(T) testing *(4,5)*. The effect of asphalt binder grade, aggregate type, temperature, asphalt content, and air voids were investigated in these studies by William Buttlar and Andrew Braham.

Investigation into the effect of asphalt binder grade showed no significant trends between binder grade and fracture energy. However, mixes were tested at temperatures tied to their performance grade, which is likely the reason for a lack of correlation.

Mixes with granite aggregate were found to have higher fracture energy than those with limestone, but only at low temperatures. Limestone aggregate mixes were shown to have higher fracture energy than granite mixes at high temperatures.

Definitive conclusions were presented on temperature and fracture energy. As testing temperature decreases, so does fracture energy. At low temperatures, the asphalt mixtures become more brittle, leading to decreased fracture energy and higher crack susceptibility.

Additional asphalt content (in excess of Superpave optimum binder level) was shown to have little effect on the fracture energy at low and mid-level temperatures. Only at high temperatures was increased asphalt content shown to increase the fracture energy of asphalt mixes.

Surprisingly, these studies found no correlation between fracture energy and air void content. While this is the case for DC(T) specimens compared between 4% and 7% air voids, it is interestingly not the case for semi-circular bend (SCB) specimens. A small investigation by Marasteanu *(6)* found significantly decreased fracture energy for SCB specimens with 7% air voids as opposed to 4% air voids.

Additional studies utilizing DC(T) testing by Sarfraz Ahmed and William Buttlar shed light on the effect of gradation types and fracture energy. Special gradations, such as dense and gap graded mixes, were shown to have higher fracture energy than those of traditional gradations *(7)*. Michael Wagoner's research included investigation into the effect of specimen thickness on DC(T) results *(8)*. Fracture energy was shown to increase significantly with increased specimen thickness. Fracture mechanics principles suggest that

increased fracture energy due to increased thickness may be the result of additional confining pressure *(9)*.

Additional studies by other universities validate the effectiveness of DC(T) testing for fracture energy. A study by the University of New Hampshire examined the DC(T) test and concluded that it can successfully identify asphalt mixtures more prone to low temperature cracking by detecting low fracture energy *(10)*. Unfortunately, the DC(T) geometry and test specifications are limiting. DC(T) testing only applies tension to specimens, whereas thermal cracking can be the results of both tension and compression. Additionally, DC(T) specifications are not the easiest in terms of testing efficiency.

In the late 1990s, researchers in the Netherlands began to apply a semi-circular bend (SCB) geometry to test AC mixture crack growth *(11)*. This test geometry, previously employed in rock fracture mechanics *(12)*, utilizes a geometry that undergoes both tension and compression, is simple to fabricate, and can be operated at room temperatures. In the mid-2000s, the Louisiana Transportation Research Center and Louisiana State University brought this test to the United States, and found it to be a promising tool for evaluating fracture resistance of asphalt materials *(13)*. These researchers used an elasto-plastic fracture mechanics concept called the critical strain energy release rate, otherwise known as the critical value of the J-integral (J_c)to investigate the asphalt concrete materials.

Research by the University of Illinois at the Illinois Center for Transportation (ICT) further honed the capabilities of the SCB test. The report *Testing Protocols to Ensure Performance of High Asphalt Binder Replacement Mixes Using RAP and RAS* (*14)* details the process by which the ICT further refined the SCB method in order to more effectively characterize

cracking potential. Extensive testing validated a 50-millimeter-per-minute strain-controlled test at 25° C to be ideal for differentiating between asphalt mixtures *(15)*. However, fracture energy, used as the critical factor in DC(T) analysis, was found to be an insufficient parameter to define fracture curves. The ICT determined that fracture energy can be identical for asphalt mixtures that display entirely different fracture properties. Figure 1.1 presents a visualization of this phenomenon.

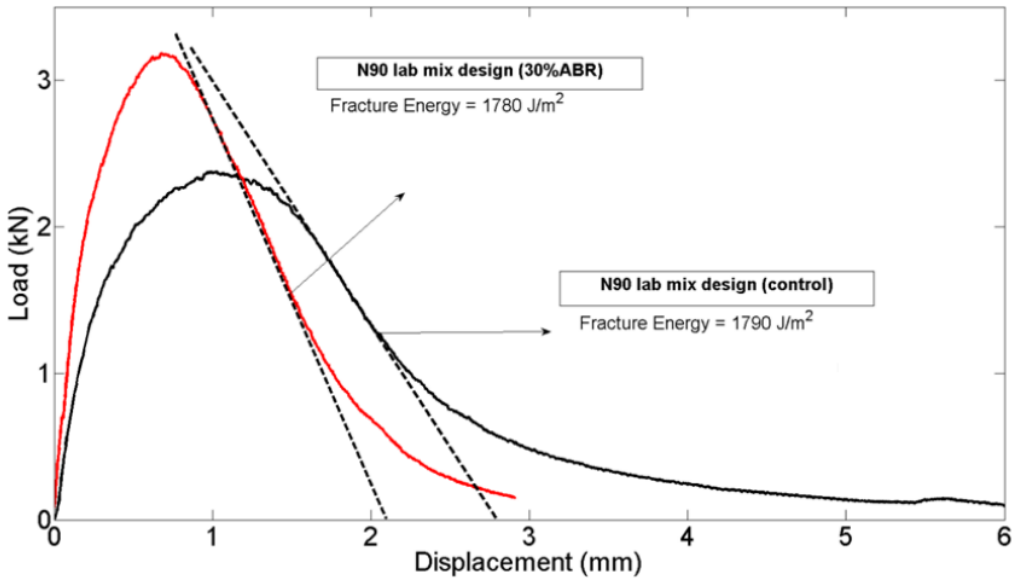


Figure 1.1 I-FIT Fracture Curves with Similar Fracture Energy

Fracture energy is defined as the area under the load-displacement curve normalized to the area of crack propagation. Figure 1.1 presents how two entirely different types of fracture curve can display the same fracture energy. Fracture curves similar to the control mix, in black, which require more displacement to achieve complete fracture, are more ductile. Fracture curves similar to the mixture displayed in red, which have higher peak loads but take less time to propagate, are more brittle. The cracking resistance of an asphalt mixture is therefore likely dependent on the shape of the fracture curve *(16,17)*.

As a result, the ICT developed the flexibility index (FI), which properly characterizes the fracture energy and shape of SCB fracture curves, so as to more effectively characterize the cracking potential of an asphalt mixture design. The ICT's method, called the Illinois Flexibility Index Test (I-FIT), is defined in detail in Section 3.1. This thesis, as a whole, evaluates the effects of certain impact factors on the Illinois Flexibility Index Test, to develop greater insight into the I-FIT method.

The I-FIT method is in the preliminary stages of implementation as a part of a balanced mix design procedure for the Illinois Department of Transportation (IDOT). Ideally, an asphalt mixture should be stiff enough to withstand rutting at high temperatures and flexible enough to withstand cracking at low temperatures. This is the concept behind a balanced mix design, supported by the research of Mogawer et al *(18)*. This current research suggests the I-FIT method can successfully predict cracking potential, and is therefore ideal for balanced mix design testing.

The Texas Department of Transportation (TXDOT) has investigated a balanced design procedure, which includes the Hamburg Wheel Tracking test and the Texas Overlay Test *(19)*. Early investigation indicated that the current Hamburg procedure is sufficient, and that minimum repetitions to cracking failure in the Texas Overlay Test requirement should be implemented based on climate, traffic, and existing pavement conditions *(20)*. The Louisiana Department of Transportation and Development (LaDOTD) has implemented a procedure that again includes the Hamburg Wheel, but uses an SCB geometry J-integral critical value (J_c) for low temperature cracking potential *(21)*. IDOT is currently seeking to implement a superior form of balanced mix design by utilizing already-required Hamburg

testing and adding the I-FIT method to ensure asphalt mixes are properly designed against cracking failure.

With an understanding of the process that led to the development of the I-FIT method, the topic of brittleness mitigation can be properly investigated. With continued use of asphalt binder replacement, which can cause excessive brittleness, strategies of brittleness mitigation must be investigated. Since the I-FIT method is ideal for identifying brittle and flexible asphalt mixtures, it is also ideal for evaluating the success of brittleness mitigation strategies. Of particular interest to this thesis is an atypical method of brittleness mitigation: the use of mix-applied rejuvenation.

The effect of rejuvenation on asphalt binder properties is a well-researched topic. Asphalt rejuvenators are used as a softening agent, intended to mitigate excessive stiffness from high ABR levels. In order to comprehend the mechanics of rejuvenation, an understanding of asphalt binder chemical composition is necessary.

Research indicates that asphalt chemical composition influences material stiffness. R. Grover Allen chemically divided asphalt binder into four subgroups—Saturates, Aromatics, Resins, and Asphaltenes (referred to together as SARA)—and evaluated the composition's effect on binder properties. Differences in composition can lead to either an increase or decrease in binder stiffness. High levels of asphaltenes are likely to increase binder stiffness, while high levels of aromatic hydrocarbons are likely to decrease stiffness *(22)*.

The addition of aromatic oils to asphalt binder has been shown to decrease binder stiffness. A study by the Worchester Polytechnic Institute *(23)* studied the effect of six aromatic oils on Superpave performance grade. The six rejuvenators were waste vegetable oil, waste

vegetable grease, organic oil, distilled tall oil, aromatic extract, and waste engine oil. All six rejuvenators, when applied at 12% dosage (by binder weight) to a stiff ABR binder, were able to return the binder to its original performance grade.

A similar study by Clemson University came to parallel conclusions. Adding rejuvenator to aged binders led to an increase in binder fatigue resistance, but a decrease in binder rutting resistance, synonymous with the goal of softening the binder *(24)*. Again, the Indian Institute of Technology found similar conclusions when mixing Pongamia oil and composite castor oil with binder. Mixing these rejuvenators with binder was again shown to improve fatigue characteristics of the binder, but decrease the rutting resistance of the binder *(25)*.

In general, review of literature suggests that the application of aromatic oil rejuvenators successfully softens an asphalt binder, which should increase crack resistance and decrease rut resistance. Currently lacking is research into the effectiveness of rejuvenation on mixture performance testing and the effect of aging on rejuvenated asphalt mixtures. Consequently, these are major focuses of this thesis.

In summary, fracture energy of asphalt materials is a well-researched topic, specifically via DC(T) and SCB testing. However, the testing results are incapable of distinguishing between asphalt concrete mixture's susceptibility to cracking. In addition, while the fracture energy is well investigated, the shape of fracture curves is not. Investigation into the I-FIT method will provide insight into the effect of several impact factors on the shape of fracture curves and their fracture energy. Additionally, the effect of rejuvenation on binder performance is well understood, but research into rejuvenated mixture

performance is lacking. The I-FIT method is ideal for evaluating the impact of rejuvenation on mixture performance; therefore, it is employed to investigate the effectiveness of rejuvenation as a brittleness mitigation strategy.

1.2. Problem Statement

The Illinois Flexibility Index Test (I-FIT) has been shown to effectively characterize the flexibility of an asphalt mixture design and, subsequently, its cracking potential. While the test has been shown to be effective, it is in its early stages, and several influential factors on the test are not yet understood.

I-FIT specimen specification is strict, so as to ensure that the test only captures the effects of material design. Strict requirements on geometry and density are imposed so they do not influence results. However, for field cores, these impact factors may be uncontrolled. Careful investigation into these factors is necessary, so as to gain a greater understanding of the I-FIT method and to ensure proper analysis of field cores.

With a greater understanding of the I-FIT method, we can use it for its ideal purpose: to investigate methods of increasing the flexibility of brittle asphalt mixtures. Evaluation of excessive asphalt mixture brittleness as a result of high recycled content is the primary goal of the I-FIT method. The method can also effectively be used to observe increases in flexibility as a result of mixture brittleness mitigation strategies.

Asphalt mixture brittleness mitigation strategies are necessary for the future of asphalt paving if the heavy use of recycled materials is to continue. The flexibility index (FI) is an ideal parameter to evaluate the effectiveness of these strategies, whether they be typical or atypical. A typical strategy of mitigating excessive brittleness is the use of a softer virgin

binder, while atypical strategies employed to increase the flexibility of an asphalt mixture include increasing binder content or adding a rejuvenator to a mix. Using the I-FIT method, these strategies can be evaluated.

1.3. Research Scope

Twelve surface asphalt concrete (AC) mixes were evaluated via the I-FIT method, using both plant mix and field cores. Trends are observed for differing sources and levels of asphalt binder replacement (ABR), including both recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS). The effect of binder softening is observed, as well as the addition of atypical aggregates, such as crushed concrete and steel slag (Section 3.2).

I-FIT specification calls for specimens of a certain thickness; however, this thickness may not always be possible to attain. Field cores, in the case of a thin overlay, may not be thick enough to attain the required thickness. Variation in I-FIT results as a function of thickness must therefore be understood, and this is investigated in Section 3.3–3.4.

Additionally, air void content is carefully controlled by I-FIT specification in the case of laboratory-produced specimens. Field cores, on the other hand, may have variable air void contents and are likely outside of the recommended range in I-FIT specification. It is therefore vital to have a comprehensive understanding of the effect of air void content on I-FIT results, which is investigated in Section 3.5–3.6. The results of field core testing outside of thickness and air void specification are observed and compared with plant mix results in Sections 3.7–3.8.

Brittleness mitigation strategies are investigated in Chapter 4. Of particular interest is the effect of mix-applied rejuvenation on I-FIT results. A softening paraffinic oil, Hydrolene

H90T, is employed for these studies. The effect on I-FIT results of adding the rejuvenator in different dosages and volumetric designs is observed (Section 4.1–4.2). Also investigated is the effect of aging on rejuvenated I-FIT results, so as to ensure that these strategies of brittleness mitigation are effective in the long term (Section 4.3). Additional aging investigations for compacted and loose mixtures are conducted to attain a greater understanding of the effect of aging on I-FIT fracture curves (Section 4.3–4.4).

Lastly, the process of mixture-applied rejuvenation is related to an existing construction procedure, hot-in-place recycling (HIR). Stiffness in field cores is mitigated via mix-applied rejuvenation and analyzed with the I-FIT method, so as to effectively quantify trends in flexibility while closely resembling HIR (Section 4.5).

Additionally, the rutting resistance of rejuvenated field cores is investigated in Section 4.6. The trade-off that exists between flexibility and rut resistance requires investigating the effect of mix-applied rejuvenation on rut resistance. A method of optimizing HIR rejuvenator dosage is presented in Section 4.7, dependent on rutting failure, with the goal of maximized flexibility.

1.4. Research Impact

As a whole, the topics of this thesis present a wider and more fine-tuned understanding of the I-FIT method, as well as its possible applications. Analysis of the effect of thickness and air voids will allow for more effective evaluation of field core I-FIT testing. Understanding the effect of aging on I-FIT results will provide insight into time dependent cracking resistance, and may have an impact on industry. Evaluation of brittleness mitigation strategies via the I-FIT method will prove invaluable when selecting methods of mitigating

excessive stiffness due to high recycled content, which will become more and more necessary as issues with recycled asphalt mixtures continue.

2. Testing Materials

2.1. Asphalt Concrete Surface Mix Materials

Twelve surface AC mixes are included as part of the investigation. All projects are located within 40 miles of each other, in Joliet and the western and south suburbs of Chicago. This minimizes any environmental effect on the performance. The 12 AC mixes have varying types and levels of ABR, as presented in Table 2.1 *(26).* This allows studying the effect of various types and levels of recycled materials. Plant mix was unavailable for Wolf Road. Basic details for the 12 surface AC mixes are provided in Table 2.1.

Table 2.1 Summary of Surface AC Mixes

Mix ID	Mix Field Location	N-Design	Virgin Binder Grade	RAP (%)	RAS (%)	ABR (%)	Crushed Concrete (%)	Steel Slag (%)
157M	Crawford Ave SB	N70	58-28	9.9	5.0	29	None	None
156M	Crawford Ave NB	N70	64-22	4.9	2.5	15	None	None
140M	US 52 Chicago St. (IL 53) to Laraway Road EB	N70	58-28	20	3.1	30	None	None
159M (Y02)	US 52 Chicago St. (IL 53) to Laraway Road WB	N70	58-28	34	None	29	None	None
185M (N08)	US 52 from Laraway Road to Gouger Road	N70	52-34	39	5.0	48	29	27
185M (N07)	US 52 from Gouger Road to Second Street	N70	52-28	39	5.0	48	29	27
177M	Washington Street WB	N70	58-34	20	3.1	30	None	None
159M (Y04)	Washington Street EB	N70	58-34	34	None	29	None	None
137M	26th Street	N50	52-28	51	4.6	60	30	15
338K	Harrison Street	N50	52-28	53	5.0	56	27	15
138Z	Richards Street	N50	58-28	27	None	29	None	73
306K	Wolf Road	N70	58-28	30	None	20	None	None

2.2. Surface Mix Gradations

All mixes have a 9.5-millimeter (mm) nominal maximum aggregate size (NMAS). Gradations for each of the 12 sections follow a relatively similar trend (see Figure 2.1).

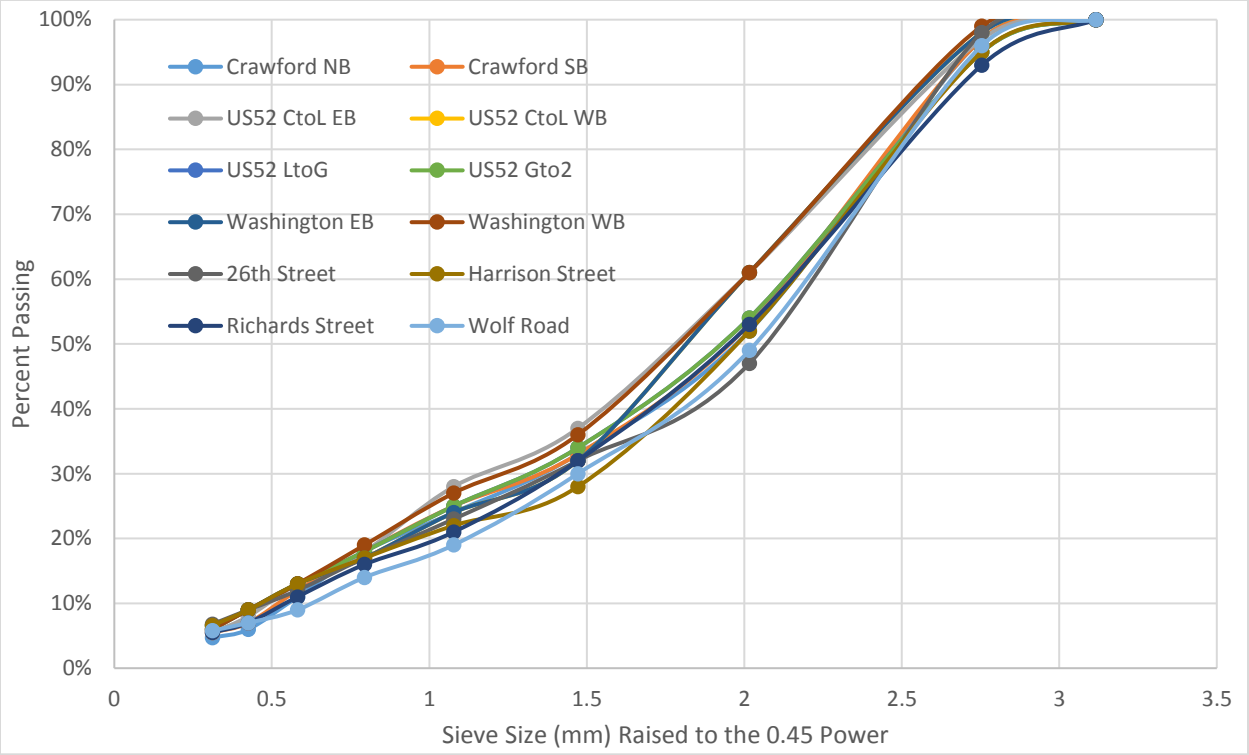


Figure 2.1 Surface AC Mix Gradations

The average standard deviation for any of the aggregate sizes does not exceed 3.3% for any of the AC mixes. The figure of gradations does display some variability, however. In order to continue with an efficient analysis of important factors on these mixes, it is essential to provide reasonable justification for omission of gradation as a factor in mixture performance as presented below.

2.3. Mixture Modulus Prediction

A popular method of predicting the dynamic modulus of an asphalt mixture is the Witczak model. The predictive model is a function of gradation, density, binder content, loading frequency, and binder viscosity. While we are currently uninterested in the dynamic modulus (E*), the model allows to predictively determine the effect of the gradation variance on mechanical properties.

The complex modulus model presented by Witczak *(27)* was used to confirm the aggregate gradation effect by holding other parameters, including air void, binder content, loading frequency, and binder viscosity, constant at V_a – 7%, V_{beff} – 5%, f – 1 Hz, and n – 0.366E5 Pas at 25° C, respectively. The Witczak model is presented in Equation 2.1, with gradation variables (i.e. p_x) as variable inputs.

$$log_{10}|E^*| = -1.249937 + 0.02923p_{200} - 0.001767(p_{200})^2 - 0.002841p_4 - 0.05809V_a - 0.082208\frac{V_{beff}}{V_{beff}+V_a} + \frac{3.871977-0.0021p_4+0.003958p_{3/8}-0.000017(p_{3/8})^2+0.00547p_{3/4}}{1+\exp(-0.603313-0.313351\log(f)-0.393532\log(n)} \quad (2.1)$$

Results for the 12 AC mixes are presented in Table 2.2. It is clear that the coefficient of variation in complex modulus related to aggregate gradation is low, at 3.9%. This relatively low COV allows us to reasonably conclude that gradation has minimum effect on the mixtures' mechanical properties, which allows us to focus on more important factors affecting these mixtures' performance.

Table 2.2 Predicted Witczak E* Values for Fixed Variables

	156M	157M	140M	159M (Y02)	185M (N08)	185M (N07)	159M (Y04)	177M	137M	338K	138Z	306K
E* (ksi)	882	908	980	975	963	963	975	961	864	945	963	893

2.4. Mixture Grouping and Discussion

A basic grouping of these AC mixes allows drawing conclusions on factors affecting the flexibility index (FI). Job mix formulas (JMFs) provide detailed summaries of each mix and justification for their groupings. JMFs can be found in Appendix A.

- Mix 156 and 157: Similarly sourced, these two mixes are designed to evaluate binder softening, as well as the acceptability of using PG 64-22, a standard binder for virgin Illinois designs, in AC mixtures with ABR.
- Mix 159 (Y02 and Y04): These mixes are designed to evaluate the effect of eliminating RAS from designs, as well as the effect of binder softening.
- Mix 140 and 177: These mixes are both similarly sourced and seek to determine if moderate levels of RAS can be mitigated by softer than standard binders.
- Mix 185 (N07 and N08): These mixes are designed with high levels of ABR, and include crushed concrete and steel slag, a concept developed by IDOT called total recycled asphalt (TRA). Softer binders are employed for both versions of the mix design.
- Mix 137 and 338: These are both TRA mixes, with differently sourced materials and softer binders. ABR levels are extreme, and an analysis of these mixes will determine if standard binder softening is sufficient to correct excessive stiffness from extreme levels of ABR.
- Mix 138: The effect of extreme levels of steel slag is observed.

3. I-FIT Testing of Plant AC Mixes and Field Cores

3.1. Illinois Flexibility Index Test (I-FIT)

All plant AC mixes and field cores were evaluated via the I-FIT method in accordance with AASHTO TP 124 *(28),* titled *Determining the Fracture Energy Parameters of Asphalt Mixtures Using the Semicircular Bend Geometry (SCB) at Intermediate Temperatures.*

Specimens are compacted in a Superpave gyratory compactor to a height of 180mm with a 150mm diameter. 7% air void content is targeted, with a tolerance of 0.5%. Specimens are cut to two 50mm slices obtained from the middle of the core. Following slicing of cores, specimens are halved and notched. Notches are cut at the center of the halved face to 10% of the diameter +/- 1.5%. This typically corresponds to a notch length of 14–16 mm, with general geometry displayed in Figure 3.1.

Field cores may not fit this specification. Layers may have been paved at less than 50mm, and air voids are likely not within the range of specification.

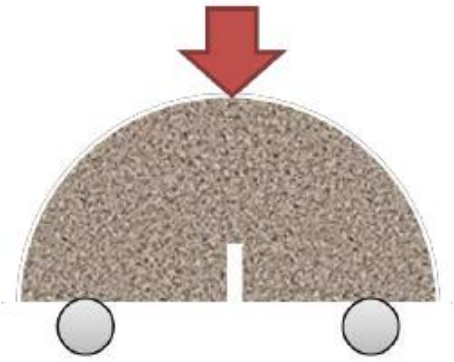


Figure 3.1 – General SCB Geometry

Specimens are positioned symmetrically in a typical three-point bending fashion. A linear variable differential transformer (LVDT) is placed to measure vertical displacement over

time. A seating load of 0.1 kN is placed to guarantee non-dynamic loading. Following the seating load, the specimen is loaded in a strain-controlled test, at a rate of 50mm/minute. Fracture is observed, and resulting loads are recorded as a function of displacement.

Resulting data follows the typical form in Figure 3.2. Specimens reach a peak load, at which point cracking becomes visible. At the peak load, specimens fracture and load decreases to zero.

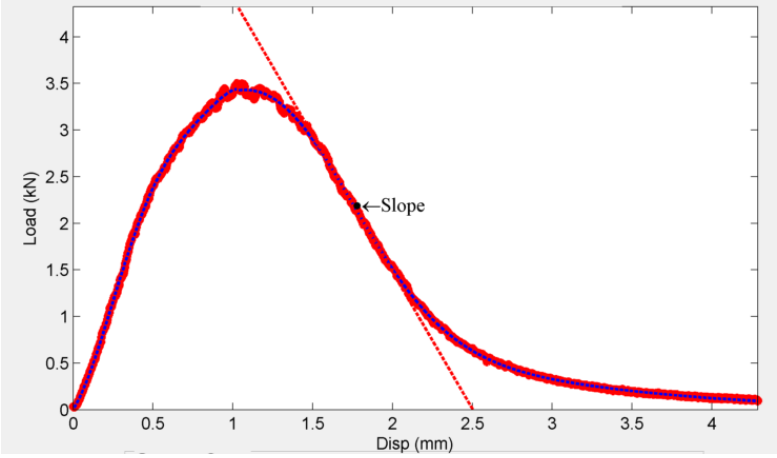


Figure 3.2 Typical I-FIT Load Response Curve

Two vital parameters are recorded from the fracture curve. First is the fracture energy (Equation 3.1), which is the area under the load (*L)* displacement (*D)* curve, or the energy necessary to propagate the crack, normalized to the ligament area. Fracture energy is measured until a residual load of 0.1kN. The ligament area is the area over which the crack propagates, measured from the notch tip to the edge of the specimen.

$$Fracture\ Energy\ (G_f) = \frac{\int_0^{D(0.1\ kN)} L\ (D)\ dD\ (Joules)}{Ligament\ Area\ (m^2)} \tag{3.1}$$

The fracture energy alone is not enough to characterize the curve. As explained in Section 1.1, curve shapes may vary while having equivalent fracture energies. Some curves may be

more rounded and take more time to propagate. Curves of this sort are considered more flexible. This is quantified using the slope at the post-peak inflection point, defined in Equation 3.2.

$$Slope\ (m) = \frac{dL}{dD}\ at\ Post\ Peak\ Point\ of\ Inflection \tag{3.2}$$

Using the above two values, the flexibility index (FI) was obtained, and is presented in Equation 3.3. This index characterizes the cracking resistance of asphalt mixtures.

$$FI = \frac{Fracture\ Energy\ (G_f)}{Absolute\ Value\ of\ Slope\ (abs(m))} * A \tag{3.3}$$

$$A = .01\ (for\ more\ convenient\ index\ values)$$

From a single Superpave specimen, four I-FIT tests can be conducted, and results are averaged. For field cores, two cores are used to obtain four I-FIT tests. Higher values of FI correspond with higher flexibility and less brittle behavior. For reference, IDOT considers a mix with an FI of 8 or higher a "good" mix.

3.2. Plant Mix Test Results and Discussion

Several hundred kilograms of each plant AC mix were sampled and transported to the ICT in Rantoul, Illinois, where they were stored. AC mixes were not tested on similar time frames; some tests were performed as soon as two and a half weeks after sampling, while others were tested almost three years after sampling. Hence, storage period could have had an impact on the I-FIT outcome. Table 3.1 presents I-FIT results, including fracture energy, slope, and FI for each surface AC mix, along with their storage aging. A discussion of results for each mix follows.

Table 3.1 Plant Mix I-FIT Results

Field Location	Mix Design	Storage Aging (Days)	Fracture Energy (Joules/m^2)	Slope (kN/mm)	FI
Crawford NB	**156M**	155	2095	-4.5	4.8
Crawford SB	**157M**	155	1912	-5.5	3.5
US52 CtoL EB	**140M**	122	1791	-2.7	6.6
US52 CtoL WB	**159M (Y02)**	122	2138	-2.2	10.4
US52 LtoG	**185M (N08)**	77	1271	-2.9	4.7
US52 Gto2	**185M (N07)**	17	1396	-2.0	7.2
Washington EB	**159M (Y04)**	83	1739	-1.6	11.9
Washington WB	**177M**	83	1872	-1.8	10.6
26th Street	**137M**	921	1686	-4.5	3.8
Harrison Street	**338K**	991	1146	-13.5	0.9
Richards Street	**138Z**	903	2476	-4.9	4.1

Crawford Avenue Northbound (156M). This mix is a prime example of PG 64-22 virgin binder grade being an improper binder to use in a mix with ABR. While this mix only has 15% ABR, mostly from RAS, its FI is relatively low, at 4.8. PG 64-22, while ideal for virgin mix designs in Illinois, is not appropriate for mixes with ABR.

Crawford Avenue Southbound (157M). This mix uses the same materials as Mix 156M, but uses a softer binder (PG 58-28) and has additional ABR (30%). This ABR levels comes from

10% RAP and 4% RAS. Again, the FI is low, at 3.5. While using a softer binder may have mitigated some issues from the additional ABR, it did not bring the values to an acceptable value. Mix 157M shows that when RAS levels are too high (i.e., 4%), the resultant flexibility decrease may not be able to be mitigated by conventional methods.

US 52 Eastbound from Chicago to Laraway – Mix 140M. This mix also attempts to mitigate issues of high ABR by using a softer binder (PG 58-28). This mix also has 30% ABR, but when compared with Mix 157M, more ABR content comes from RAP, with only 2.5% of the mix being RAS. This mix has a FI of 6.6, a somewhat acceptable value, especially when compared with Mixes 156 and 157. These results show that the use of a softer binder can mitigate certain moderate levels of RAS.

Washington Street Westbound – Mix 177M. This mix is designed very similarly to Mix 140M, also with 20% RAP and 2.5% RAS, for a total ABR of 30%. A softer binder is used (PG 58-34), and the results are evident in the FI. Mix 177M has a flexibility of 10.6, indicating again that a softer binder can mitigate certain moderate levels of RAS. This design also shows that PG 58-34 is much more effective than PG 58-28 at mitigating stiffness, when compared to Mix 140M.

US 52 Westbound from Chicago to Laraway – Mix 159M (Y02). This mix is the first example without RAS. This mix has approximately 30% ABR, all of which is from RAP, and a resulting FI of 10.4. Its results show that high levels of decreased flexibility are primarily the result of RAS content and not RAP content. Using a virgin binder of PG 58-28 is shown to be an acceptable method of mitigating ABR stiffness if ABR is solely from RAP.

Washington Street Eastbound – Mix 159M (Y04). This mix has the same design as 159M (Y02), but an even softer binder is used, PG 58-34. This results in an even higher FI, at 11.9. Again it is shown that acceptable flexibility can be attained with the use of a softer binder, when the only source of ABR is RAP, and not RAS.

US 52 from Gouger to Second Street – Mix 185M (N07). This mix is a total recycle asphalt mix, or TRA, comprised of RAS, RAP, steel slag, and crushed concrete, with almost 50% ABR. Mix 185M (N07) is reported to have a binder grade of PG 58-28 and has an FI of 7.2. This shows that the mix, despite having irregular components and high recycled content, can be brought to an acceptable flexibility by using a softer binder.

US 52 from Laraway to Gouger Road – Mix 185M (N08). This mix has the same design as 185M (N07), but is reported to use a softer binder (PG 52-34). Contrary to expectations, the FI decreases, with a value of 4.7. It is possible that Mix 185(N08)'s longer storage aging, compared to Mix 185(N07), adversely affected its FI results. Regardless of storage aging, the very similar Mix 185M (N07) displays acceptable flexibility index (FI=7.2), indicating that a softer binder can mitigate a mix of atypical aggregates and high ABR.

26th Street – Mix 137M. This mix is another TRA mix, composed of RAP, RAS, steel slag, and crushed concrete, with a virgin binder grade of PG 52-28. The FI was determined to be 3.8, indicating a low flexibility mix. This shows that for a TRA mix with ABR percentages as high as 60%, it may not be possible to mitigate low flexibility with a softer binder.

Harrison Street – Mix 338K. This mix is a TRA mix similar in components (slightly more RAS) and virgin binder grade to Mix 137M. Unfortunately, it has an FI less than 1. The mixture had a very high absorption rate, at 1.7%, where a typical mix will have a rate of

about 1.4%. This is possibly the result of the type of crushed concrete used. The high absorption likely led to the mix being "dry," which increased its brittleness. The high percentage of RAS (5%) likely brought the FI to unacceptable levels as well.

Richards Street – Mix 138Z. This mix is almost entirely steel slag (72.5%), has normal levels of ABR (30%), and has no RAS. While the FI results were not ideal, at 4.1, the fracture energy of this mix is worth discussing. On average, the other mixes have a fracture energy of around 1700 joules per square meter, but this mix has a fracture energy of 2476 joules per square meter. While the high slope brings the FI down, this extremely high fracture energy may be beneficial to the mix design. The high fracture energy suggests excellent bonding between steel slag and asphalt binder.

General Conclusions. Binder softening is shown to be an effective method of increasing FI. PG 64-22 is shown to be an improper binder grade to use for ABR mixes in the Illinois climate. For AC mixtures with moderate RAS levels (e.g. 2.5%), binder softening can bring FI to acceptable levels. However, in certain cases, such as those with high RAS content (e.g. 4% or higher), binder softening may be inadequate. AC mixes with no RAS display higher FI values than those with RAS present. AC mixes with moderate levels of ABR solely from RAP display good FI values.

TRA mixes with near and above 50% ABR all have low FIs. It may not be possible to increase TRA FIs to acceptable levels using only conventional approaches (e.g., binder softening). Lastly, steel slag content is shown to significantly increase the fracture energy of an asphalt concrete mixture.

3.3. Impact of Thickness on I-FIT Results

Field cores undergoing I-FIT testing may not have the required thickness (50mm) to accomplish standard I-FIT specification. It is therefore necessary to study the effect of thickness on I-FIT parameters, so as to fully understand the change in fracture mechanics as a result of specimen thickness.

To analyze the effect of thickness on I-FIT parameters, a wide spectrum of thicknesses was evaluated in increments of 10mm, from 10 to 60mm. A 4.75 NMAS leveling binder AC mix, with Mix ID 163 (N07), was selected for the comparison because of its low NMAS, in order to guarantee that thin specimens could be fabricated and be relatively homogenous. Additionally, a surface mixture (Mix ID 159M[Y04]) with NMAS of 9.5mm was tested to ensure trends remain similar with different mixture types.

Figure 3.3 provides the load as a function of displacement for each of the six thicknesses. Each curve is an average of the four tests performed at each thickness. With decreasing thickness, a decrease in area under the curve (work of fracture) was observed. Also observed with decreasing thickness was a decrease in slope at post-peak inflection point.

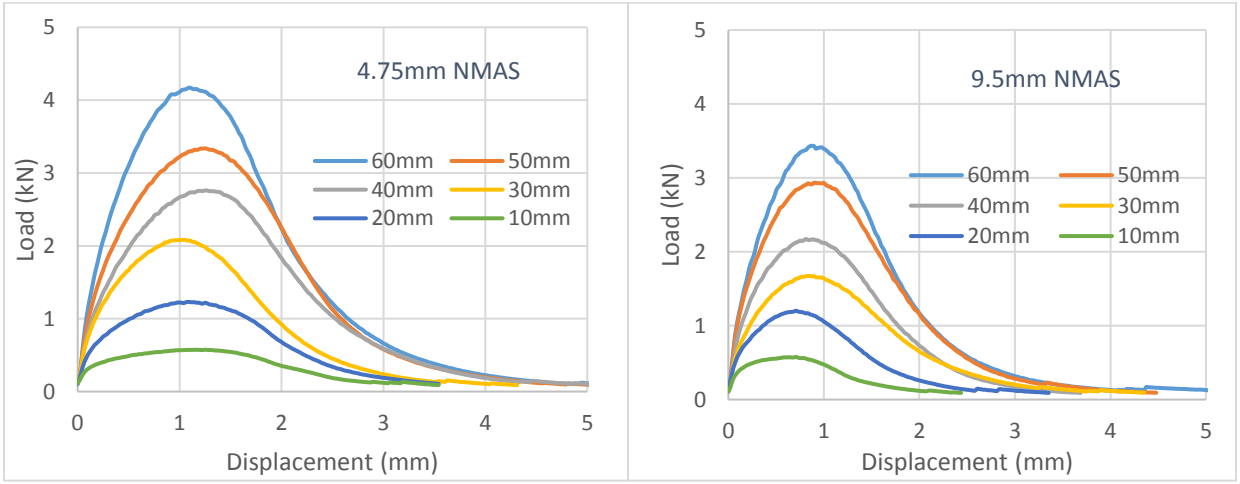


Figure 3.3 Thickness Testing Raw Data Curves

3.4. Thickness Correction Factor Development

Since field cores may be thinner than I-FIT specification requirements, it is necessary to develop a correction factor for thickness. This will allow comparison between standard 50-mm-thick specimens and field core specimens with lower than required thickness.

Four I-FIT specimens were tested at each thickness level, and error bars in Figures 3.4-3.6 indicate standard deviations. The relationship between the work of fracture (energy), fracture energy (energy normalized to ligament area), and thickness is displayed in Figure 3.4. Normalization to ligament area, already included in the I-FIT method, is shown to be an acceptable method of eliminating fracture energy thickness dependence. However, a drop in fracture energy at lower thicknesses for both materials is observed. Increased confining pressure with thicker specimens and transition from plane-strain to plane-stress can result in higher crack front resistance *(9)*.

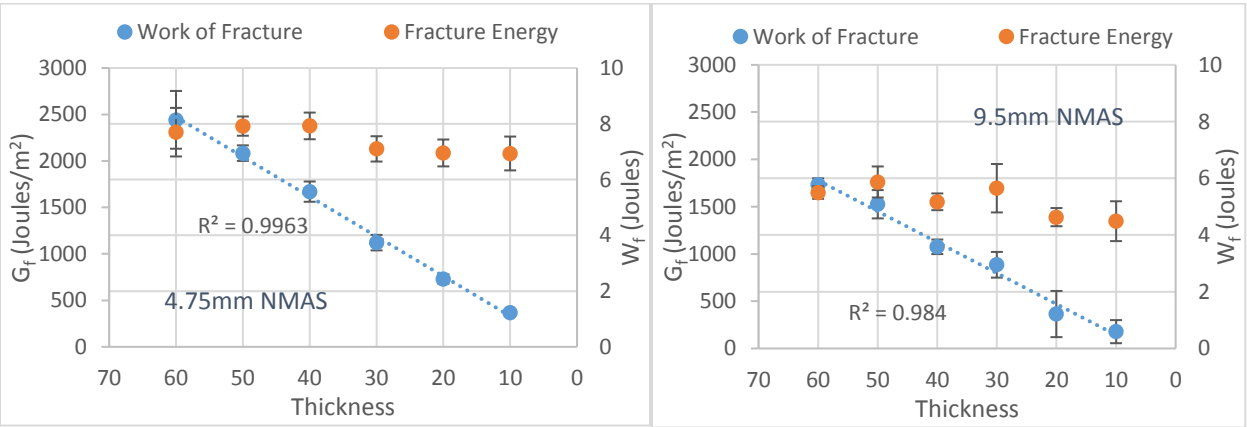


Figure 3.4 Thickness and Fracture Energy

Additionally, the effect of thickness on the slope must be investigated in order to create a correction factor for the FI. Slope decreases linearly with decreasing thickness (see Figure 3.5). Therefore, a simple normalization to the standard 50mm thickness is sufficient to

correct the slope. It is worth noting that the correction, presented in Equation 3.4, is less successful at very low thicknesses.

$$m_{Thickness-Corrected} = m * \frac{50}{T} \tag{3.4}$$

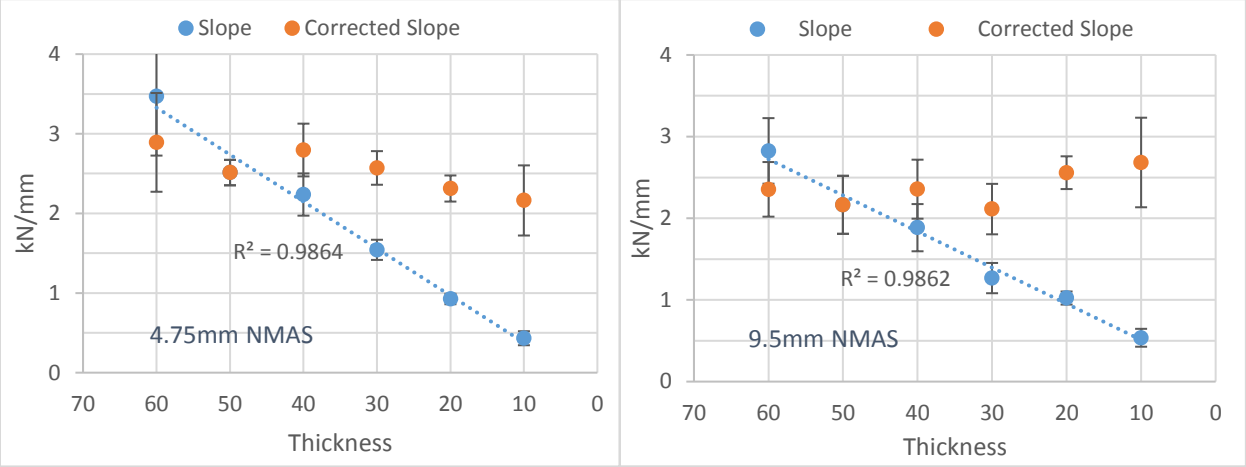


Figure 3.5 Thickness and Slope Correction

Incorporating the slope thickness correction, the following correction for the FI was obtained, presented in Equation 3.5, with success observed in Figure 3.6.

$$FI_{Thickness-Corrected} = \frac{G_f}{m_{T-Corrected}} = \frac{G_f}{m*\frac{50}{T}} \tag{3.5}$$

$$FI_{Thickness-Corrected} = \frac{G_f T}{50m}$$

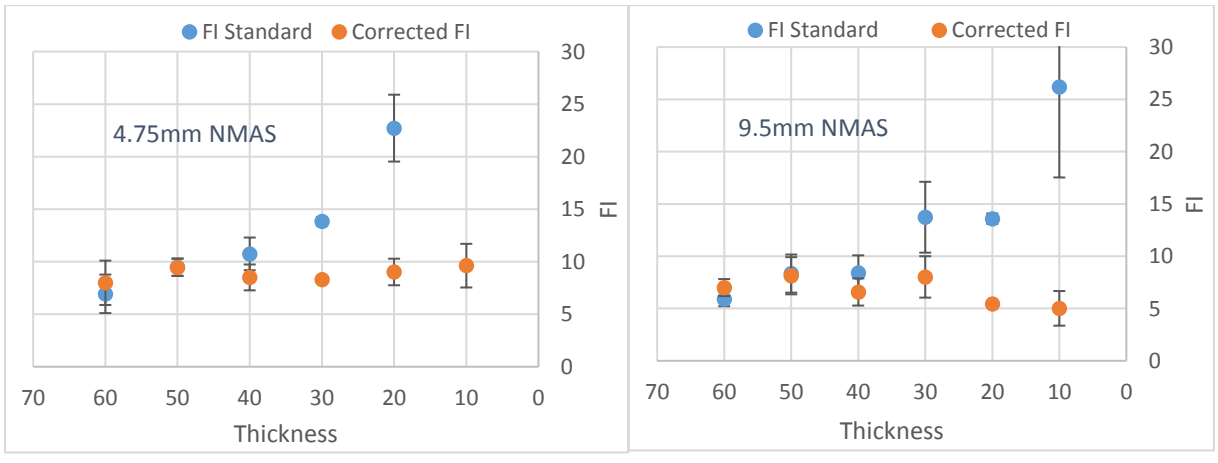


Figure 3.6 Thickness and Corrected FI

Corrected FI values for the 4.75mm mix average to FI=8.8, within one point of the standard 50mm FI of 9.5. Variation of corrected values is also relatively low, with a COV of 7.5%. These values are indicative of a successful correction for the 4.75mm mix.

Average corrected FI for the 9.5mm mix is 6.7, with a standard 50mm FI value of 8.3. This correction is less successful than the 4.75mm correction, primarily due to low corrected values for low thickness (10 mm and 20 mm). As the thickness of specimens approaches the NMAS, the correction factor loses accuracy. It is therefore recommended to avoid testing at thicknesses near the NMAS. Excluding 10mm and 20mm thick 9.5mm NMAS specimens, the average corrected FI is 7.4 with a COV of 10.3%, within one point of the standard FI of 8.3 and with relatively low variation.

An F-test, factoring in fit of linear regression and correlation, can also determine the effectiveness of the correction factor. The null hypothesis of a zero slope of linear regression between thickness and uncorrected and corrected FI is tested. Low p-values indicate high levels of certainty of correlation, while high p-values are indicative of eliminated correlation and a successful correction.

For the 4.75mm NMAS mix, an uncorrected FI has a p-value of **0.0298**, indicating a high likelihood of correlation. A corrected FI has a p-value of **0.268**. The high increase in p-values from uncorrected to corrected FI values is indicative of elimination of correlation and a successful correction.

For the 9.5mm NMAS mix, the correction is effective with the exception of low thicknesses of 10 and 20mm. The p-value for uncorrected FI is **0.016**, corrected FI is **0.132**, and **0.728** when 10mm and 20mm specimens are excluded. The correction is very successful when

specimens are not too thin in relation to their NMAS. It is therefore recommended to avoid testing at thicknesses below 2.5 times the NMAS. Considering layers are rarely constructed at less than 3 times the material NMAS, this is a practical restriction. Equation 3.6 is suggested for correcting FI values for variable thickness, with T being the specimen thickness in millimeters.

$$FI_{Thickness-Corrected} = FI * \frac{T}{50} \tag{3.6}$$

$$T \geq 2.5 * NMAS\ (Recommended)$$

3.5. Impact of Air Voids on I-FIT Results

Laboratory-produced specimens allow for carefully controlled air void levels, with a small range of acceptability at 6.5–7.5%. Specimens obtained from the field may contain anywhere from 0–10% air voids. The effect of air voids on FI parameters must therefore be understood. The same 4.75mm and 9.5mm NMAS mixes used in Sections 3.3–3.4 are employed for observing the effect air voids on I-FIT parameters. Effects on I-FIT fracture curves are displayed in Figure 3.7.

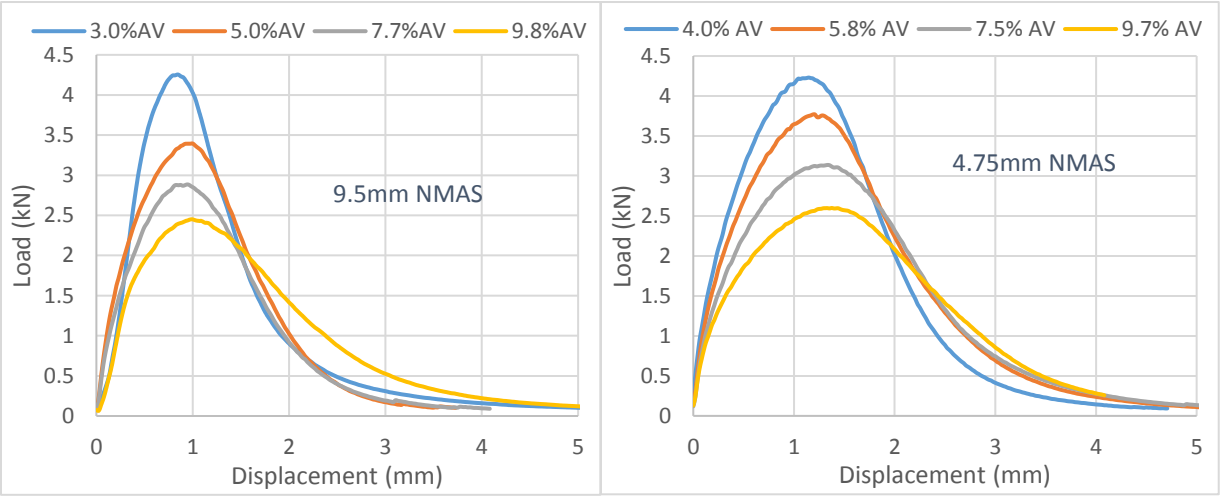


Figure 3.7 Air Voids and I-FIT Fracture Curves

A consistent decrease in peak load with increased air void content is observed for both mixes. A less significant decrease in fracture energy is observed with increasing air void content for both mixes. Additionally, a significant and consistent decrease in slope is observed with increasing air voids. Figure 3.8 presents these trends in a quantifiable manner. Data points are individual I-FIT tests. Testing on the 9.5mm NMAS mixture is more extensive, but similar trends are encountered for both mixes.

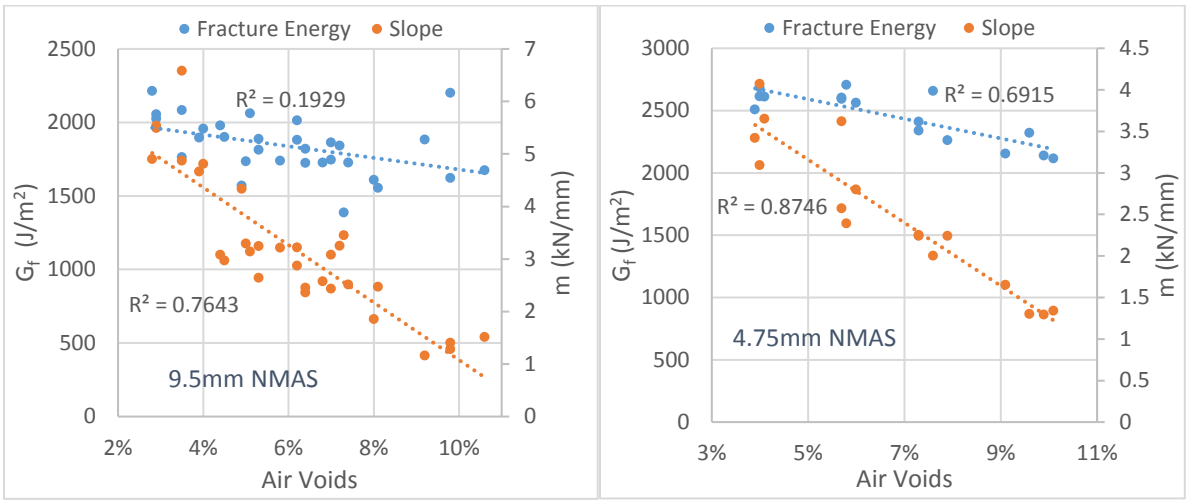


Figure 3.8 Air Voids and I-FIT Parameters

Both parameters of the FI decrease with increasing air voids. The slope displays a stronger correlation with air void content than the fracture energy. Slope decreases are more relatively rapid than fracture energy decreases, leading to an increase in FI with increasing air void content. This trend is presented in Figure 3.9, with data points aggregated to 4-test averages for simplification. Error bars represent FI and air void standard deviations within a single Superpave gyratory specimen.

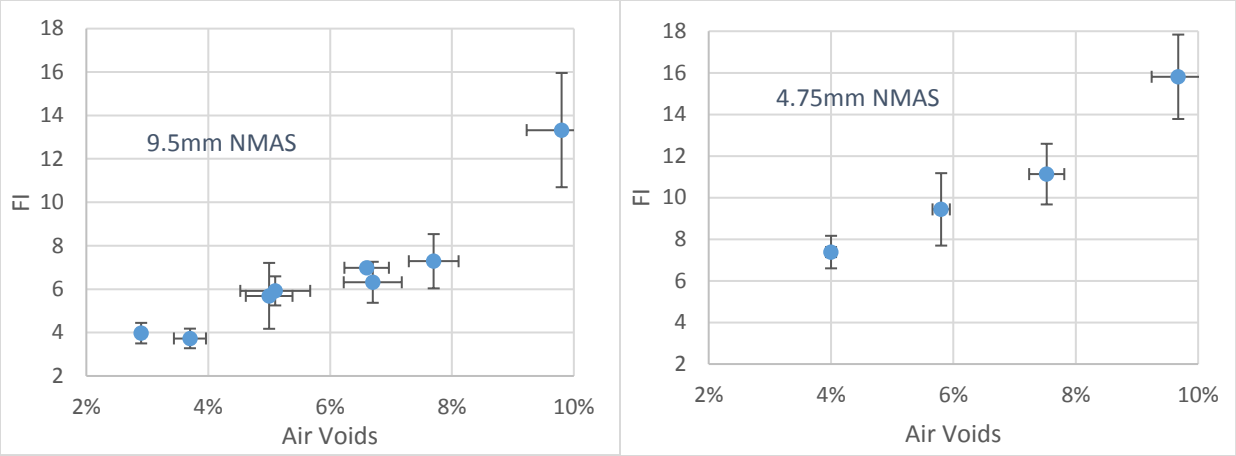


Figure 3.9 Air Voids and Flexibility Index

While investigation by Marasteanu *(6)* into fracture energy as a cracking resistance parameter suggested that lower air void contents are preferable, FI analysis suggests the opposite. Previous investigation by Harvey and Tsai *(29)* suggested that lower air void content increases fatigue life, adding further evidence that lower air voids are preferred for extending asphalt pavement life. Additionally, extended research has shown that lower air void content increases the dynamic modulus of asphalt concrete *(30)*.

Although the FI does increase with increasing air voids, that fact should not be taken as a recommendation to increase air voids in order to decrease cracking potential. Rather, strict volumetric control should be adhered to when using the I-FIT method as an evaluation tool for material properties. In addition, increasing air void content would have a negative impact on rutting.

3.6. Air Void Correction Factor Development

Since air voids have been shown to affect the FI, and field core air void contents are variable, it is necessary to investigate a correction factor for air voids. An air void correction factor will guarantee that only material properties are being compared, as

opposed to the effects of different air void contents. Both parameters of the FI were shown to be dependent on air void content; therefore, the parameters must be investigated separately to develop an ultimate correction factor.

Hypothetically, for laboratory-compacted specimens at 7% air voids, 93% of the ligament area is particle contact area over which the crack propagates. When air voids fall outside this range, there is a change in contact area, and fracture energy should be normalized as such, which is presented in Equation 3.7. AV is the air void content as a decimal. Figure 3.10 presents the results of this correction.

$$G_{f\ AV-Corrected} = G_f * \frac{.93}{1-AV} \tag{3.7}$$

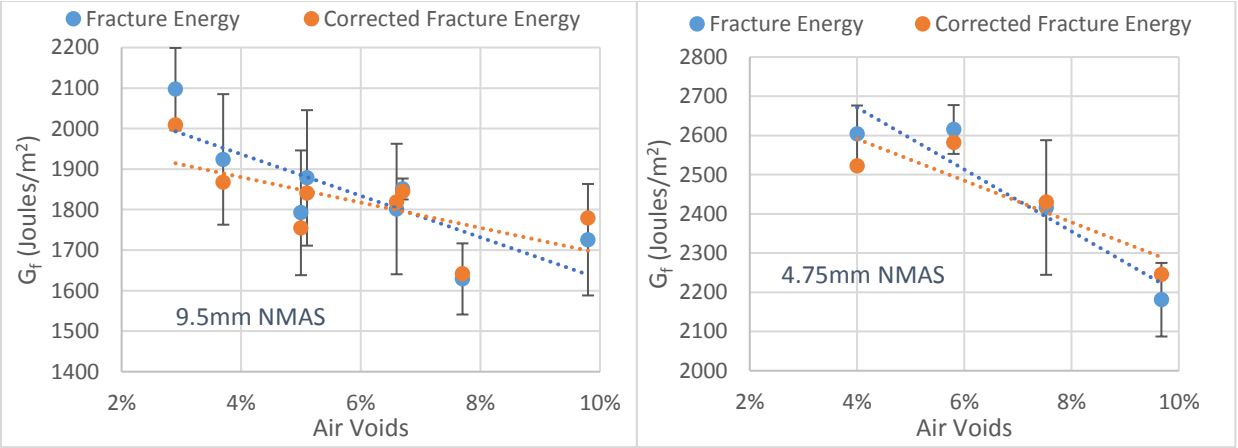


Figure 3.10 Air Void Correction for Fracture Energy

Corrected fracture energy values are brought closer to their hypothetical 7% air void fracture energy; however, the correction does not completely adjust some fracture energy values. Variability in fracture energy, denoted by standard deviation error bars, makes it difficult to discern the effectiveness of this correction.

Recall that correlation between fracture energy and air void content is relatively weak, when compared with slope correlation. Consequently, the slope correction is much more vital. It will be shown that with an effective slope correction, fracture energy corrections are minor, and the previously described method is sufficient.

The slope decreases relatively more rapidly than fracture energy. Instead of normalizing to the desired contact area (93%), slopes are normalized to the desired void space (7%). This ensures a higher degree of correction, as is necessary for the slope's higher air void dependency. The slope correction is presented in Equation 3.8 with its effectiveness presented in Figure 3.11.

$$m_{AV-Corrected} = m * \frac{AV}{0.07} \tag{3.8}$$

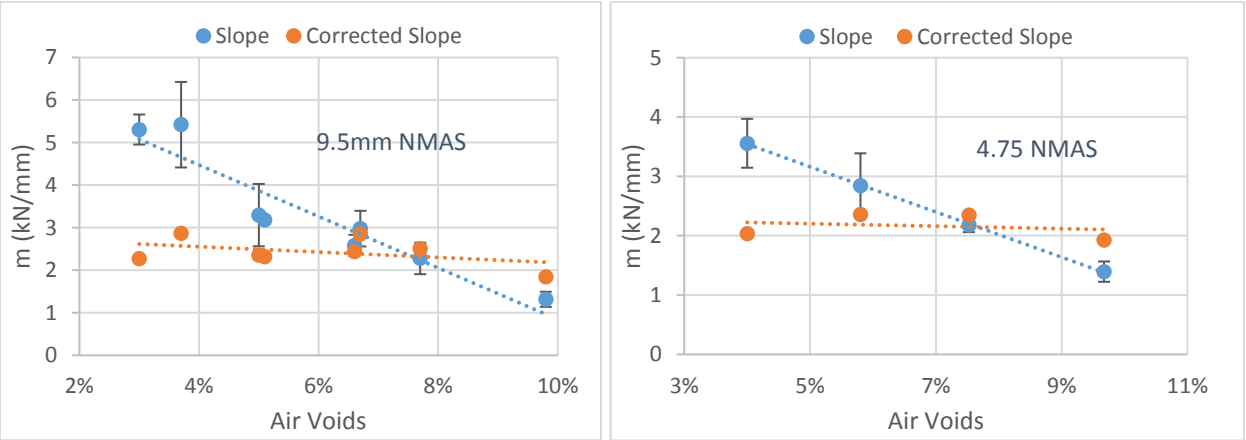


Figure 3.11 Air Void Correction for Slope

Slope-air void dependency is effectively eliminated for both mixes. This correction allows for the successful correction of the FI for variable air void content. Some variability remains, but it is within the typical variance of slope values, displayed by the error bars. Combining the two corrected parameters, we obtain the air void corrected equation for FI, presented in Equation 3.9. Figure 3.12 presents the results of the air void correction.

$$FI_{AV-Corrected} = FI * \frac{0.0651}{AV-AV^2} \quad (3.9)$$

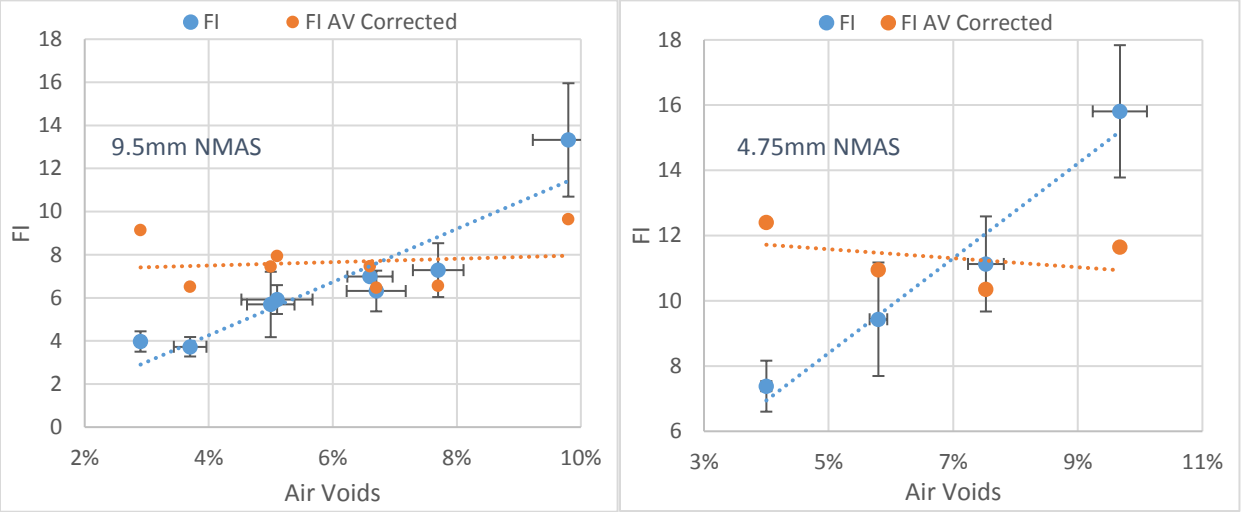


Figure 3.12 FI Air Void Correction

A linear projection of 9.5mm NMAS FI predicts an FI of 8.0 at 7% air voids. The eight corrected FI values have an average of 7.7, with a coefficient of variation of 15.8%. The corrected FI average is extremely close to the expected 7% FI, and has a coefficient of variation typical of FI results. Similarly, the 4.75mm NMAS mixture has an expected FI of 11.3 at 7% air voids, and a corrected average of 11.3, with a coefficient of variation of 7.8%. These values indicate success in the correction for air voids for both mixtures.

A statistical analysis of the air void correction for the 9.5mm NMAS mix, performed similarly to that presented in Section 3.4, yields an uncorrected p-value of 0.00097, a near certainty of correlation, and a corrected p-value of 0.643, again indicating a successful correction. Similarly, the 4.75mm NMAS mix yields an uncorrected p-value of 0.0034 and an increased corrected p-value of 0.103.

All of the above statistical analysis indicates a successful correction for air voids. Additionally, Figure 3.12 presents strong cause for the success of the developed correction

factor for variable air voids effect on the FI. However, increased corrected error at extremely low and high air voids was observed for the 9.5mm NMAS mixture. Therefore, caution is recommended for I-FIT testing below 3% or above 9% air voids.

3.7. Field Core I-FIT Test Results

Thickness and air voids are the two immediately noticeable differences between field cores and plant mix I-FIT specimens, hence their investigation in Sections 3.3–3.6. Since surface AC mixes were compacted in a thin overlay, a maximum specimen thickness of 30mm was obtained for each, as opposed to the 50mm standard for plant AC mix. Air voids are uncontrolled in the field, with section averages ranging from 0.4–8.8%, as opposed to the specified 6.5–7.5% for plant AC mix.

Field core FIs are higher than their plant AC mix counterparts (see Table 3.1 and 3.2). Higher FIs are primarily the result of lower slopes, not differing fracture energy. Field core load response curves follow significantly different shapes than their plant AC mix counterparts, but experience similar fracture energy when normalized to the different ligament areas. Despite having Mix 137M placed in both directions, 26th Street experienced significantly different FIs in opposite directions. Air voids are significantly different for 26th Street directions.

Table 3.2 Field Core I-FIT Results

Field Location	Mix Design	Air Voids (%)	Fracture Energy (Joules/m²)	Slope (kN/mm)	FI
Crawford NB	**156M**	7.6	1786	-2.3	8.0
Crawford SB	**157M**	4.6	2158	-2.1	11.3
US52 CtoL EB	**140M**	6.4	2078	-1.1	19.0
US52 CtoL WB	**159M (Y02)**	8.8	2257	-1.8	12.9
US52 LtoG	**185M (N08)**	4.7	1683	-0.9	18.4
US52 Gto2	**185M (N07)**	5.1	1861	-0.6	31.5
Washington EB	**159M (Y04)**	4.8	1799	-0.5	36.5
Washington WB	**177M**	3.2	1810	-1.1	17.0
26th Street	**137M**	EB: 5.8 WB: 2.2	EB: 1738 WB: 2553	EB:-2.2 WB:-0.8	EB: 8.9 WB: 31.5
Harrison Street	**338K**	3.3	1594	-4.5	4.0
Richards Street	**138Z**	0.4	3114	-1.7	18.7
Wolf Road	**306K**	2.7	2529	-1.5	17.9

3.8. Comparison of Plant Mix and Field Core I-FIT Results

Recalling Tables 3.1 and 3.2, the differences in field core and plant mix FIs are investigated. Field core FIs are significantly higher than their plant mix counterparts for most surface

mixes. In an attempt to eliminate this difference, the correction factors developed for thickness and air void content are employed.

Recall that field core thicknesses are approximately 30mm. Therefore, applying the thickness correction developed in Section 3.4, all field core FIs should be reduced by approximately a 30/50 factor, in order to represent proper geometry. The thickness correction usually reduces the difference in FI values between field cores and their plant mix counterparts.

The air void correction factor, when applied to field cores, is unsuccessful. Most field core sections have air voids lower than 7%. Therefore, the trends developed in Section 3.5 would suggest that field core FI values are improperly low. Unfortunately, this is not the case when comparing field core I-FIT results with their plant mix counterparts. Applying the air void correction to field cores only increases the field core FI values, bringing them further from the plant mix FI values, with many adjustments being entirely unreasonable. For this reason, application of the air void correction is excluded. While it is possible that plant mix FI results are inappropriately low (as explained in Section 4.4), it is highly unlikely that air void differences are the primary cause of higher FI values in field cores.

Degree of correction is used to quantify the percentage of eliminated difference, as shown in Equation 3.10 and utilized in Table 3.3. Degrees of correction near 100% indicate complete correction, percentages between 0–100% indicate incomplete but proper direction correction, and negative degrees of correction indicate that field core FIs were adjusted further away from plant mix FIs. Figure 3.13 and Table 3.3 present the results of

surface AC field core corrections. Note that only the thickness correction is included, as the air void correction is unsuccessful on the field core I-FIT results.

$$Degree\ of\ Correction = 1 - \frac{|Field\ Corrected\ FI\ vs.\ Plant\ FI - \%\ Difference|}{|Field\ Uncorrected\ FI\ vs.\ Plant\ FI - \%\ Difference|} \quad (3.10)$$

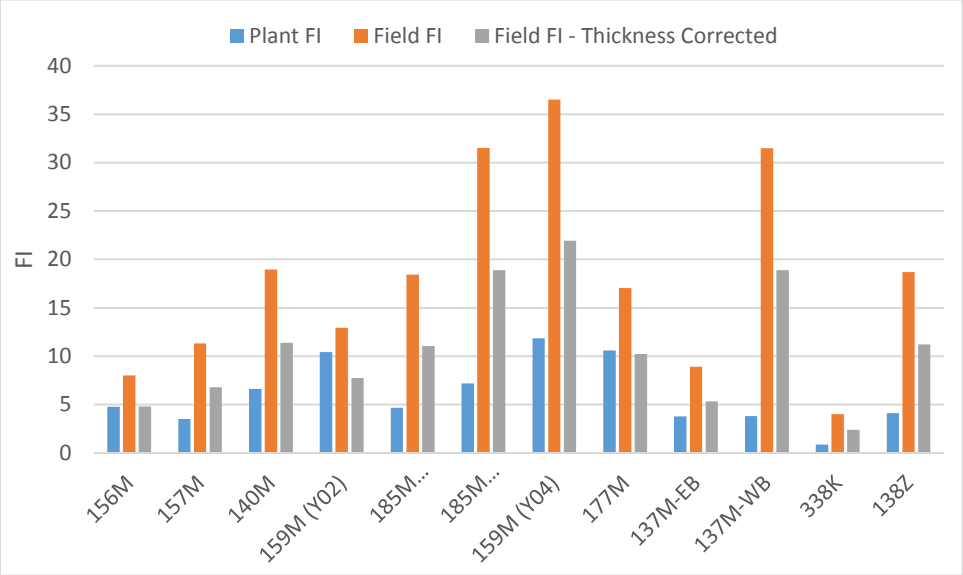


Figure 3.13 Surface AC Mix: Plant, Field, and Thickness-Corrected FI

Table 3.3 Surface AC Mix: Plant, Field, and Thickness-Corrected FI

		PLANT FI	FIELD FI	FIELD FI Thickness Corrected	Degree of Correction (%)
Crawford NB	**156M**	4.8	8.0	4.8	100
Crawford SB	**157M**	3.5	11.3	6.8	58
US52 CtoL EB	**140M**	6.6	19.0	11.4	62
US52 CtoL WB	**159M (Y02)**	10.4	12.9	7.8	-6
US52 LtoG	**185M (N08)**	4.7	18.4	11.1	54
US52 Gto2	**185M (N07)**	7.2	31.5	18.9	52
Washington EB	**159M (Y04)**	11.9	36.5	21.9	59
Washington WB	**177M**	10.6	17.0	10.2	94
26th Street	**137M**	3.8	EB: 8.9 WB: 31.5	EB: 5.3 WB: 18.9	EB: 71 WB: 45
Harrison Street	**338K**	0.9	4.0	2.4	51
Richards Street	**138Z**	4.1	18.7	11.2	51

Mix 156M and 177M are completely corrected by the thickness correction (Equation 3.6). All other mixes, except for Mix 159 (Y02), are corrected with a degree of correction ranging from approximately 50% to 70%. While these are good degrees of correction, most surface AC mixes still indicate a high level of difference between plant AC mix FI and thickness-corrected field FI because of extreme initial uncorrected differences, as shown in Figure 3.13.

Lack of field compaction control and differences in field core and plant mix aging are likely the causes of differences in FIs for thickness-corrected field core and plant AC mix. Field compaction, while by the same method for most sections, may have several uncontrolled and unrecorded variable factors, while plant mix compaction is highly controlled for each mix. However, what is highly uncontrolled, and likely the contributing factor to I-FIT differences, is variation in mixture aging.

Loose mix aging is a parameter that is likely highly influential for I-FIT results. Further evidence for this is presented in Chapter 4. Please note that plant mixes were stored loose in an uncontrolled climate and were tested at different time intervals. The time from production to testing varied anywhere from 17 to 991 days, depending on the mix. Additionally, for field sections, loose mix aging in the form of silo storage and transport time is unknown, and likely variable. It is highly likely that unknown differences in loose mix aging contributed to the differences in I-FIT results. The investigation in Chapter 4 suggests that the degree of loose mix aging contributes significantly to the shape of I-FIT fracture curves, but not to the fracture energy. This is in line with our observations of plant mix and field cores yielding similar fracture energy but different slopes.

4. AC Mix Rejuvenation Effect on I-FIT Parameters

With a greater understanding of the Illinois Flexibility Index Test developed in Chapter 3, brittleness mitigation strategies can be analyzed via the I-FIT method. With the increasing use of asphalt binder replacement, strategies for decreasing mixture brittleness are necessary. The I-FIT method is ideal for evaluating the effectiveness of these developed strategies.

This chapter analyzes the effect of mix-applied rejuvenation on I-FIT parameters. A softening agent was applied directly to loose mix in several different methods to observe changes in I-FIT parameters. The effects of rejuvenator dosage level and design are closely investigated, along with the effect of aging on I-FIT parameters. Mix-applied rejuvenation is also attempted on field specimens, in order to closely resemble a certain construction procedure: hot-in-place recycling (HIR). Additionally, interesting conclusions are presented on the effect of aging on I-FIT fracture curves.

4.1. Rejuvenator Dosage Effect on I-FIT Parameters

In this section, a rejuvenator is applied directly to a loose plant mix, and then specimens are produced in typical fashion. The effect of varying dosages of rejuvenator on I-FIT parameters is observed, with the goal of mitigating stiffness and increasing the FI. In this section, the density of specimens is maintained as the design is altered with additional rejuvenator.

Mix 157 (as detailed in Table 2.1), which was selected for its excessive brittleness as a result of high RAS content and very stiff RAS binder, is the focus of this investigation. The rejuvenator of focus is Hydrolene H90T, a petroleum product produced by Sunoco *(31)*,

which is a heavy paraffinic distillate solvent extract with the appearance and viscosity of a dark brown lubricating oil. Chemically, Hydrolene H90T is a complex combination of hydrocarbons, the primary constituent being aromatic hydrocarbons with carbon numbers ranging from C20 to C50. It is also virtually free of asphaltenes, which are particles that can increase binder stiffness *(32)*. This chemical composition is ideal for softening stiff asphalt binder.

The rejuvenator was applied directly to the heated plant Mix 157M. AASHTO T 312 *(33)* was followed for mixing and compaction temperatures. Mix 157 was heated to mixing temperature (156–159^{o} C), as was the rejuvenator. The mix was poured into an asphalt mixer, directly followed by the rejuvenator. The mix and rejuvenator were then blended in the asphalt mixer to ensure dispersion.

Rejuvenator doses were applied as a percentage of binder weight. A review of literature on previous research indicated that doses up to 15% of the binder weight are typical. In order to observe trends for different rejuvenator doses, plant mix specimens were prepared at 0%, 5%, 10%, and 15% rejuvenator by binder weight. Specimens were then compacted as per Superpave gyratory compaction specification (AASHTO T 312).

I-FIT fracture curves are presented in Figure 4.1. These curves are an average of four I-FIT tests performed at each dosage level. Again, for plant mix testing, densities were maintained for each rejuvenator level, despite changes in material design.

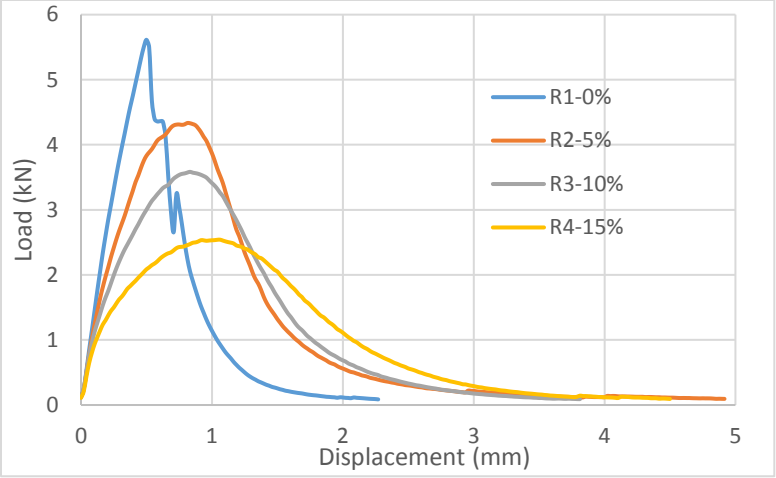


Figure 4.1 Rejuvenator Dosage I-FIT Curves

Immediately noticeable is the brittle fracture of the non-rejuvenated specimen. While Mix 157 was selected for its brittle behavior, heating the mix to mixing temperature prior to compaction likely further increased the brittleness of the mix. The fracture curve shape for the control mix shows a highly brittle failure; some specimens had nearly vertical slopes. Typically for plant mix, specimens are compacted as soon as they reach compaction temperature, as is the case for results presented in Chapter 3. The FI for Mix 157 following typical procedures is 3.5, but heating the loose mix to mixing temperature prior to compaction pushed the FI toward zero.

With increasing rejuvenator dosage, we observe a decrease in peak load, as well as a decrease in post-peak slope. Non-rejuvenated specimens (0%) proved difficult to analyze with the I-FIT method due to its brittle failure. Fracture energies were highly variable and the slope was almost vertical; therefore, both are excluded from Figure 4.2. This figure visualizes the effect of rejuvenator dosage on both fracture energy and slope. Error bars indicate the standard deviation of the four I-FIT tests performed at each rejuvenator dosage.

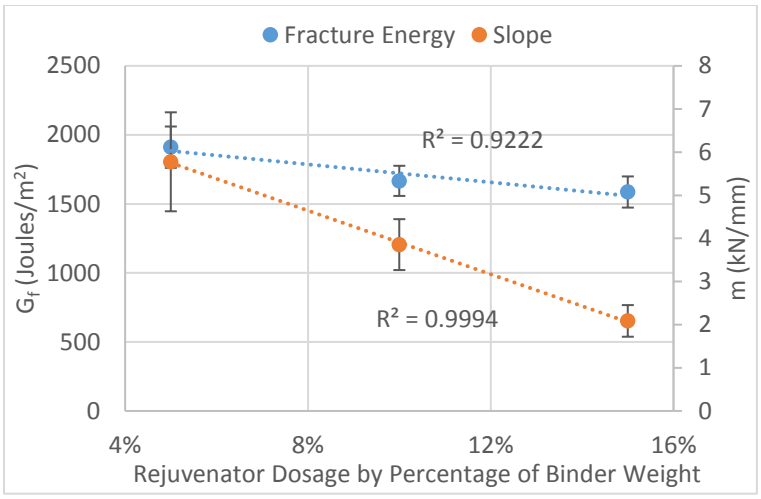


Figure 4.2 Rejuvenator Dosage and I-FIT Parameters

Fracture energy slightly decreases linearly with increased dosage. Slope also decreases linearly with increased dosage, but more rapidly. This combination of linear effects for the parameters of the FI manifests itself in a relationship between rejuvenator dosage and the FI. While both parameters of the FI are decreasing with increased rejuvenator dosage, the slope decreases at a higher relative rate than the fracture energy. This leads to a linear increase in the FI with increased dosage, presented in Figure 4.3. This also suggests the ineffectiveness of using fracture energy alone as an indication of AC crack susceptibility.

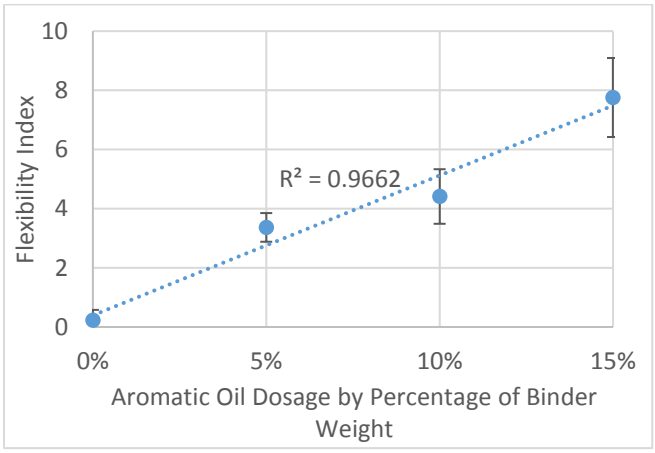


Figure 4.3 Rejuvenator Dosage and FI

These data show that applying Hydrolene H90T directly to the mix is an effective method of increasing a material's FI, taking a brittle mixture (FI overheated=0, FI typical=3.5) to an acceptable condition (FI=7.8) with a 15% dosage by binder weight. Also, a relatively linear relationship between rejuvenator dosage and FI is shown to exist for plant mix reheated to mixing temperature.

Data for each rejuvenator dosage are presented in Table 4.1. 0% dosage I-FIT results range from incalculable to 0.02 to 0.6, resulting in the high coefficient of variation. Non-rejuvenated specimen FI is effectively zero. This is different than the FI values presented in Chapter 3 for Mix 157, due to the previously described differences in heating methods.

Table 4.1 Rejuvenator Dosage I-FIT Data

Rejuvenator Dosage (%)	Fracture Energy (Joules/m²)	Slope (kN/mm)	FI	COV (%)		
				G_f	m	FI
0	Highly Variable	Nearly Vertical	0.23	19	298	155
5	1911.1	-5.8	3.37	8	20	14
10	1666.9	-3.9	4.41	7	15	21
15	1586.3	-2.1	7.76	7	18	17

4.2. Rejuvenation Design and Density Effect on I-FIT Results

Section 4.1 showed that mix-applied rejuvenation is successful when rejuvenator is applied to a standard design. This raises a question: Is the increase in FI due to the rejuvenator actually softening the material, or is it just the result of additional liquid? The analysis of laboratory-produced Mix 157 allows to answer this question, since initial design can be

manipulated (as opposed to plant mix, which could not be changed). Differences in I-FIT results between the following conceptual designs can be observed to answer this question.

- Standard design (P1)
- Standard design plus additional rejuvenator (P2)
- Standard design plus additional binder (P3)
- Standard design with less binder, filled in with rejuvenator (P4)

Dosages of 15% binder volume were used to maintain consistent volumetrics. It is also important to note that designs in this section with additional liquid were compacted to the same level as standard designs. Designs with additional liquid are therefore denser and have more voids filled with liquid than those tested in Section 4.1.

Pill 4 allows to determine if the rejuvenator itself creates significant softening when it is **not in addition** to standard binder content. Pills 2 and 3 determine the effectiveness when either binder or rejuvenator is **in addition** to standard design, and which is preferable. They also provide insight into whether keeping density or compaction effort constant is preferable by comparing with Section 4.1 results.

Average load responses are presented in Figure 4.4 and provide an understanding of the general effect of rejuvenation on each of the four designs. Figure 4.5 details the average parameters of each of the four designs. Please note that FI results for laboratory-produced Mix 157 are significantly higher than plant mix results presented in Table 3.1. Differences in production method may have led to these differences; however, the more likely reason is differences in loose mix aging. This is discussed further in Section 4.4.

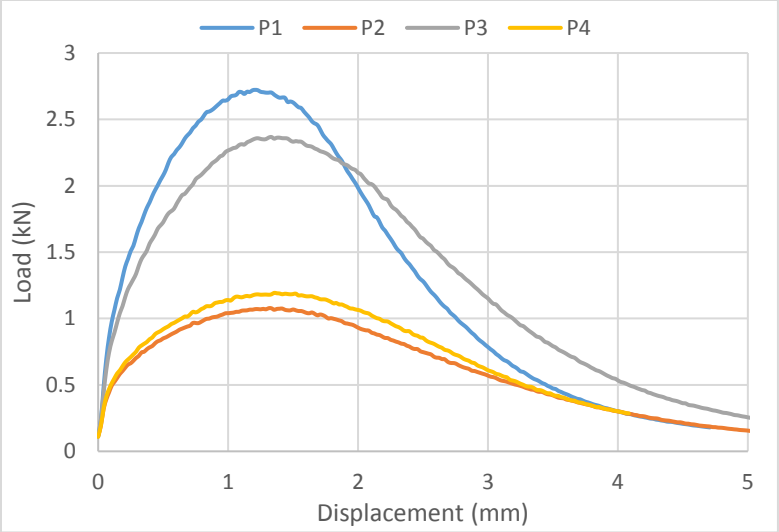


Figure 4.4 Laboratory Designed I-FIT Curves

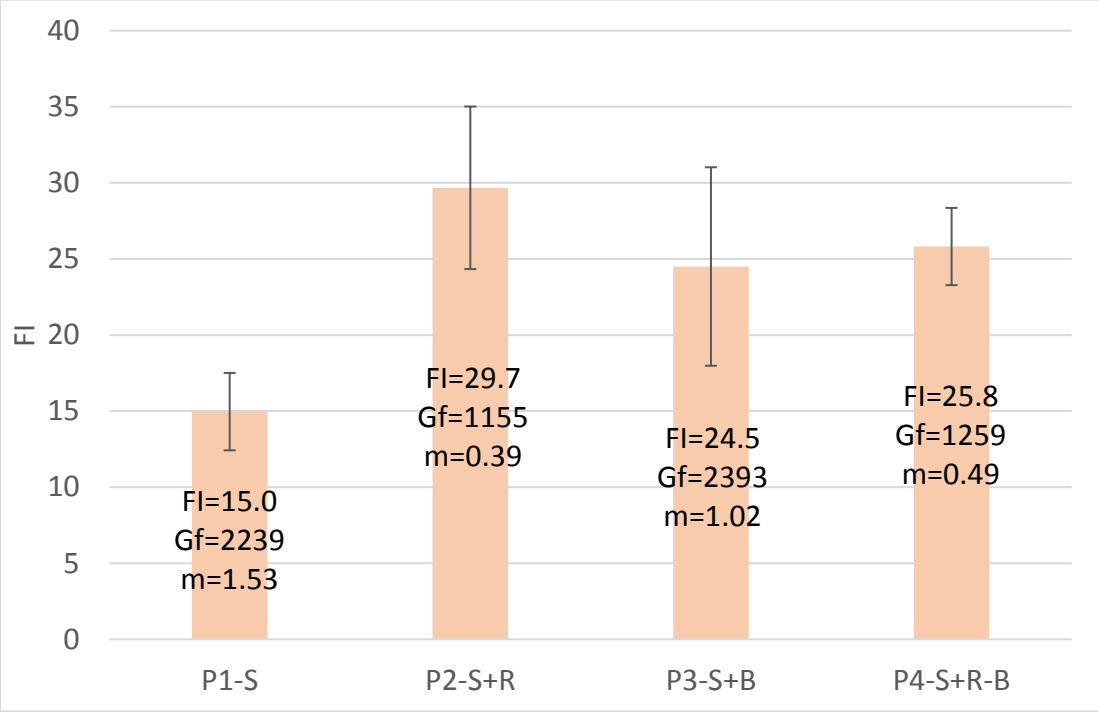


Figure 4.5 Laboratory Design I-FIT Results

P1 and P3, both with no rejuvenator present and varying levels of binder, exhibit somewhat similar fracture curves. P3 design (additional binder) yields slightly higher fracture energy and a lower slope than P1, leading to an increased FI. Adding

approximately 0.75% binder over the optimal level, while maintaining compaction design, increases the FI from 15.0 to 24.5.

P2 and P4, both with rejuvenator present, have similar curves with significantly reduced fracture energy and decreased slopes. Both observe a drastic reduction in fracture energy, at almost half factors, and decreased slopes. Pill 4 (rejuvenator replacing binder) produces an FI of 25.8, indicating that the increase in the FI is not solely the result of additional liquid and that the rejuvenator does in fact have a softening effect. Pill 2, however, observes an even greater flexibility increase (FI=29.7), indicating that rejuvenator in **addition** to a standard design is preferable to as a **replacement**, solely in terms of the FI. The superiority of Pill 2 design is the result of a lower slope and not due to fracture energy change.

The designs of Pills 2, 3, and 4 all proved to increase the FI, indicating successful stiffness mitigation. Pill 2 is the superior design in terms of the FI; however, the low fracture energy values cannot be ignored. Investigation in this section shows that the FI, when used as an evaluation parameter, can rank designs with significantly lower fracture energy as superior to mixes with higher fracture energy. Despite this, rejuvenator in addition to standard design is shown to be the superior method of increasing the FI.

Recall that this was also the method applied to plant mix in Section 4.1, which employed rejuvenator in addition to standard design while maintaining density. Section 4.2 employed the same design but compacted to standard levels. Comparing the two methods relatively, it appears that applying rejuvenator in addition to standard design, while maintaining density, results relatively in greater increase in FI than if standard compaction was

employed. Section 3.5 supports this claim, as decreases in air void content was shown to correlate with decreases in FI.

In summary, the preferred method, in terms of FI, is applying rejuvenator in addition to standard design. It is also likely that maintaining density as opposed to compaction design results in greater FI increases. Increased binder content was also shown to increase the FI, but not as effectively as rejuvenation. However, the design with increased binder content maintained fracture energy, while rejuvenation did not.

4.3. Aging Effect on Fracture Characteristics of Rejuvenated Specimens

While it has been shown that mix-applied rejuvenation is successful in mitigating asphalt mixture stiffness, this analysis only examines unaged specimens. In order to determine if rejuvenated specimens age similarly to non-rejuvenated specimens, a comparison is necessary.

SHRP-A-383 "Selection of Laboratory Aging Procedures for Asphalt-Aggregate Mixtures" (*34*) provides recommendations for aging methods for compacted asphalt mixtures. For long-term aging, it recommends aging in a forced-draft oven at 85° C for five days, which accelerates the oxidative aging processes without damaging the specimen. SHRP's recommendation is followed, with modification to aging time.

The same rejuvenated plant mix utilized in Section 4.1 (Mix 157) is used to analyze the effect of aging on rejuvenated specimens. Additionally, a reference mix—Mix 159 (Y04)—is used for comparative aging. RAS is not present in Mix 159 (Y04), and the mix has a softer binder. As a result, Mix 159 (Y04) displays acceptable flexibility without the use of rejuvenators.

Mix 159 (Y04) was selected as a comparison mix due to its similar gradation and its expected acceptable non-rejuvenated FI of 6.53, as determined by previous testing. Please note that this FI value is lower than reported in Chapter 3. By the time of Chapter 4's testing, excessive storage aging had affected the mix and decreased the FI. This effect is investigated further in Section 4.4.

Mix 157 is rejuvenated to an equivalent FI of Mix 159-Y04 (FI=6.5), so as to have equivalent starting points for the aging comparison. This is accomplished using the linear relationship derived in Section 4.1 between the rejuvenator dosage and FI. Figure 4.6 shows the linear model's prediction of necessary rejuvenator dosage to accomplish the desired FI. It also displays the actual accomplished FI using the predicted dosage.

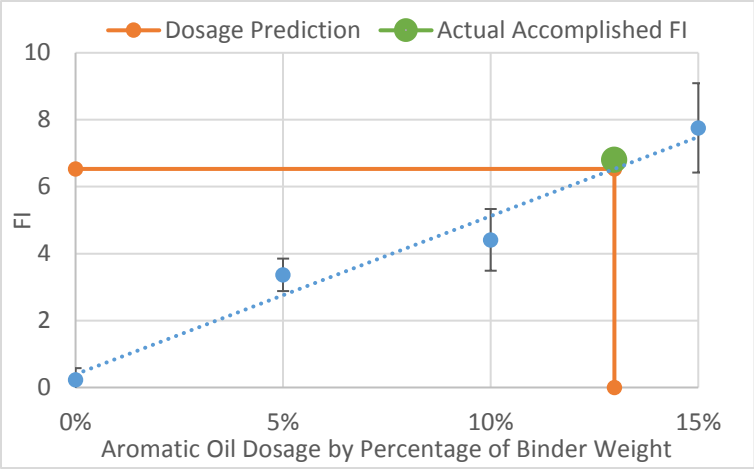


Figure 4.6 I-FIT Rejuvenation Prediction

According to the previously derived linear relationship, to accomplish an FI of 6.5, Mix 157 must be dosed with **13.0%** rejuvenator by binder weight. The green data point in Figure 4.6 graph indicates the actual result of a 13.0% dose, with a very close-to-predicted FI of **6.8**. This lends further credibility to the linear relationship.

Four pills of each mix were aged for 0, 4, and 10 days according to SHRP-recommended procedures for aging of compacted specimens. Unfortunately, previous data on the comparative mix (Mix 159[Y04]) was slightly high, as testing resulted in an average FI of 5.6, as opposed to the target of 6.5, having aged in storage additionally since its last testing. This is inconsequential in terms of the intended goal of comparison, considering the two initial points are within each other's standard deviations and the rate of change in FI can still be observed comparatively. Figure 4.7 displays the effect of aging on the FI and its parameters for both mixes, Mix 157 (rejuvenated) and Mix 159(Y04) (non-rejuvenated).

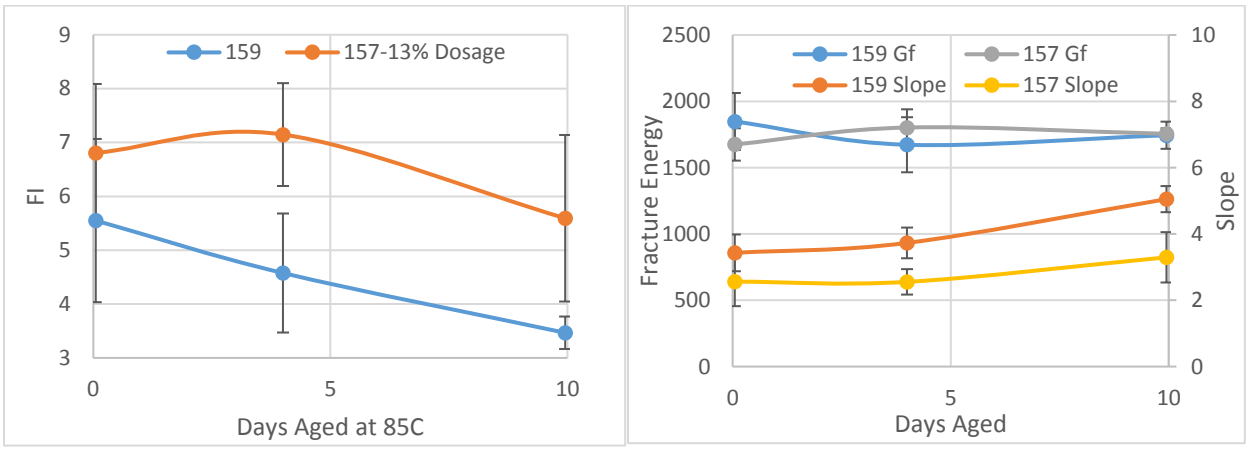


Figure 4.7 Aging and I-FIT Parameters: Rejuvenated and Non-Rejuvenated

Rejuvenated and non-rejuvenated specimens are shown to age similarly, in terms of the FI. Even with extreme aging at 10 days, the rejuvenated mix holds its FI as well as, if not better than, the non-rejuvenated mix. This indicates that specimens with mix-applied rejuvenation hold their increased flexibility through aging of compacted specimens as well as a non-rejuvenated mix.

The aging process has no statistically significant impact on fracture energy. As aging increases, however, the slope increases more and more rapidly. Mix 157 and Mix 159 (Y04) both observe similar trends in I-FIT parameters, leading to similar behaviors in their

relationship between FIs and aging. Aging likely affects the I-FIT fracture curve shape, but not the fracture energy. Average raw data curves are presented in Figure 4.8 for each mix and aging condition to visualize this phenomenon, along with parameter averages in Table 4.2.

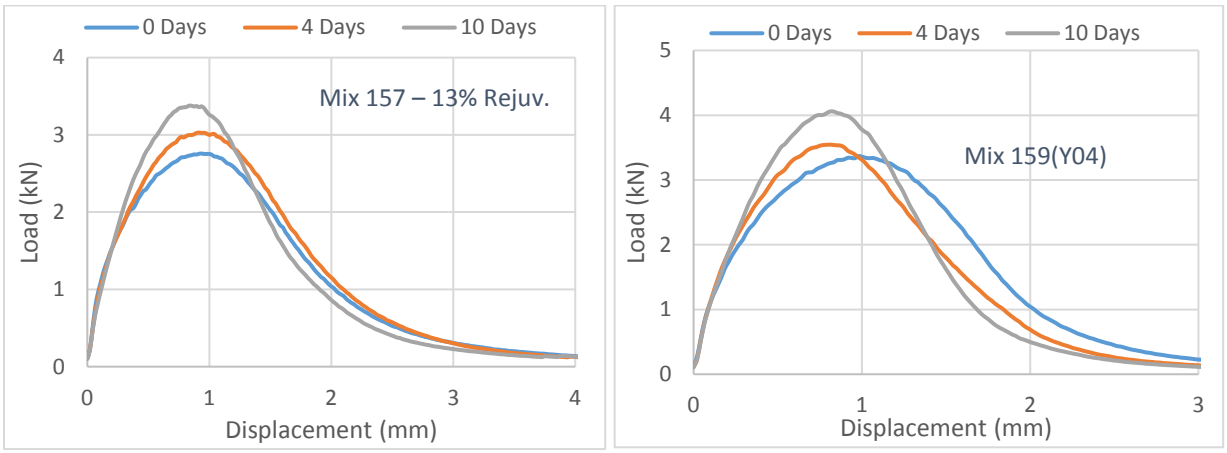


Figure 4.8 Aging and I-FIT Curves: Rejuvenated and Non-Rejuvenated

Table 4.2 Comparative Non-Rejuvenated Mix I-FIT Parameters with Age

Mix	Days Aged	Fracture Energy (Joules/m^2)	Slope (kN/mm)	FI	FI COV (%)
Mix 159: Comparative	0	1848	3.4	5.5	27
	4	1672	3.7	4.6	24
	10	1744	5.1	3.5	9
Mix 157: Rejuvenated	0	1675	2.6	6.8	19
	4	1802	2.6	7.1	13
	10	1755	3.3	5.6	28

With aging of compacted specimens, a change in the fracture shape was observed for both rejuvenated and non-rejuvenated specimens, while the area under the curve remains

relatively constant. With aging time, curves transition from more ductile fracture to more brittle.

Comparing rejuvenated aging to a non-rejuvenated counterpart, they appear to age very similarly, strictly in terms of I-FIT testing. However, plant mix likely has already undergone extensive storage aging, which may have skewed results. In order to ensure this was not the case, laboratory-produced specimens were analyzed. Aging was investigated on the P2 design from Section 4.2, and specimens were initially completely unaged to ensure all short-term aging effects were observed. To accomplish this, standard laboratory-production loose mix aging protocols were altered from the standard 2 hrs to 0 hrs.

Figure 4.9 presents the effect of aging on P2 design raw data curves, with Figure 4.10 visualizing the I-FIT parameters of said curves. P2-S+R represents 0 days aging, with P2-A aged 5 days and P2-B aged 10 days. Again, a change in I-FIT fracture curve with increased aging can be observed. However, with this case a slight increase in fracture energy with age can be observed.

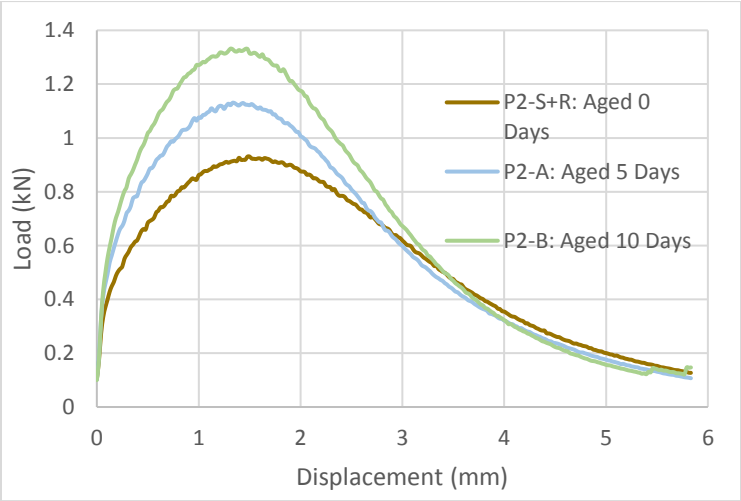


Figure 4.9 P2 Aging I-FIT Curves

I-FIT parameters and values are presented in Figure 4.10. While both parameters increase with age, the relatively more rapid increase in slope leads to a decrease in FI throughout aging. Aged rejuvenated specimens return to their non-rejuvenated FI after 5 days of aging, which SHRP-A-383 states simulates long-term aging. FI decreases beyond the non-rejuvenated FI at extreme levels of aging at 10 days. This indicates that rejuvenated specimens decrease to their non-rejuvenated FI only after SHRP-recommended long-term aging, suggesting they hold their increased flexibility relatively well.

Please note that non-rejuvenated FI for laboratory-produced specimens in this case is extremely high, at 28.2, which is indicated as the cutoff line in Figure 4.10. Recall that specimens in this analysis did not undergo the standard two-hr loose mix aging; rather, they were aged zero hrs. In this case, forgoing loose mix aging led to extremely high FIs for standard design specimens, suggesting that the FI may be extremely sensitive to loose mix aging. This phenomenon is investigated in Section 4.4.

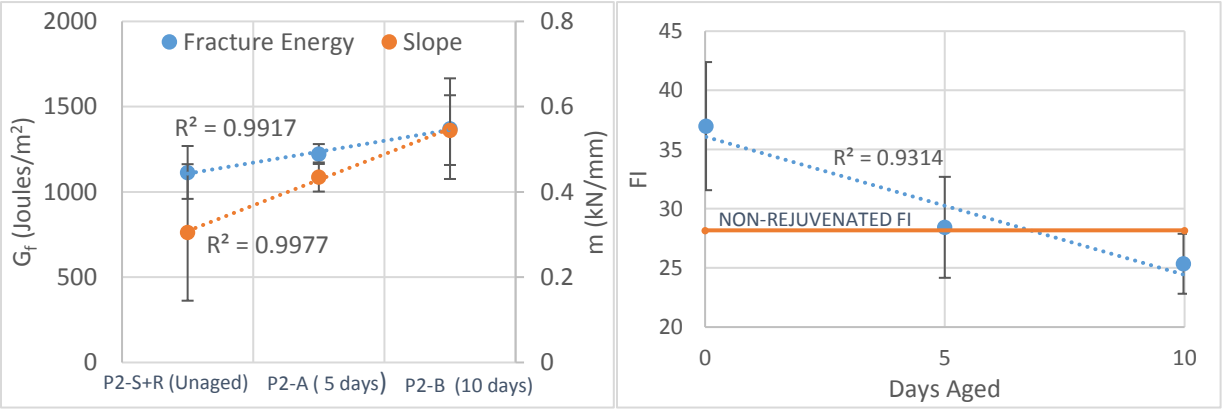


Figure 4.10 P2 Aging and FI

4.4. Effect of Loose Mix Aging on I-FIT Fracture Curves

Section 4.3 suggests that aging of compacted specimens affects the I-FIT fracture curve shape, pushing specimens from more ductile failure to more brittle failure, which consequently decreases FI values. Evidence for the influence of aging on fracture energy is less conclusive. While decreases in FI values for aging of compacted specimens were moderate, evidence in Section 4.3 suggests that the FI may be extremely sensitive to loose mix aging.

Recall that in Section 4.2, the testing of laboratory-produced Mix 157, which was exposed to two hrs of loose mix aging at 150° C, observed an FI of 15.0. When the same laboratory-produced specimen was tested at zero hrs of loose mix aging in Section 4.3, FI values of 28.2 were observed. Additionally, recalling plant mix testing of Mix 157 in Section 3.2, which was exposed to 155 days of loose mix aging in an uncontrolled climate, a low FI of 3.5 was obtained. Another piece of evidence, presented in Section 4.1, showed plant Mix 157 displaying FI values near zero when exposed to alternate loose mix aging protocols that heated the mix to 160° C prior to compaction.

All of these values indicate that the FI is likely very sensitive to loose mix aging. In order to confirm this, additional laboratory testing was performed on laboratory-produced Mix 157 aged loose at 150° C for 4 hrs. A comparison of I-FIT fracture curves for laboratory mix aged loose for zero, two, and four hrs, as well as plant mix curves, is presented in Figure 4.11. Each individual fracture curve is presented in order to prove that variation in fracture curves at individual aging states is inconsequential toward overall conclusions. Average I-FIT parameters are presented for each of the aging conditions, along with FI COV.

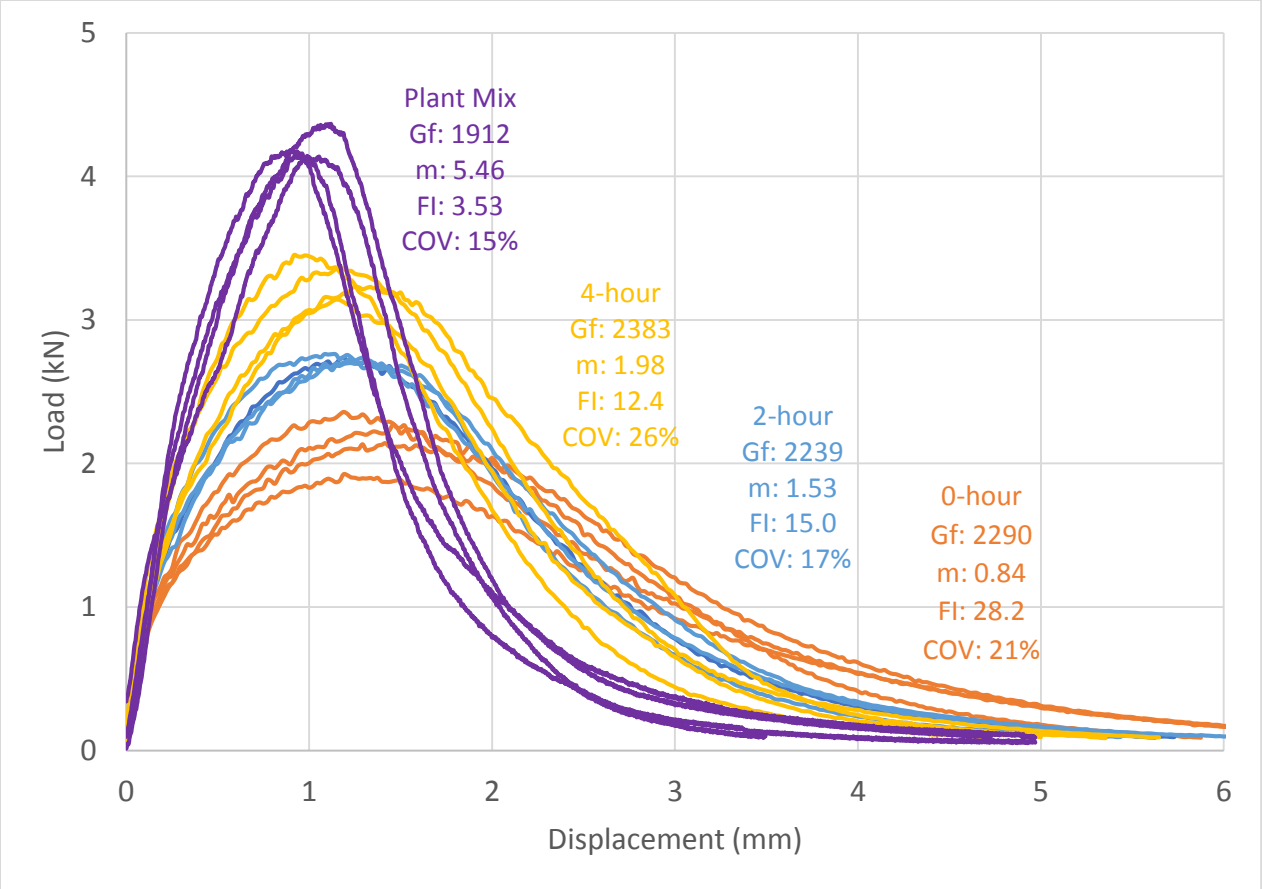


Figure 4.11 Loose Mix Aging and I-FIT Curves

Similar fracture energy is observed in all laboratory-produced mixtures despite aging conditions, while fracture energy is slightly lower for plant mix. The more significant trend observed is the consistent change in fracture shape depending on aging condition. Fracture curves are significantly different for zero, two, and four hrs loose mix aging. Curves become more brittle with age, recording higher slopes and lower FIs. Changes in fracture curves are more significant from zero to two hrs, consistent with our understanding of loose mix aging. Loose mix aging is expected to occur more rapidly in its early stages, and then decrease in rate with time. Differences in zero-, two-, and four-hr curves suggest that this is true.

Plant mix I-FIT curves may not be comparable to laboratory-produced testing. Differences in production method may be the primary cause for differences in I-FIT curves. They are included regardless, however, since the differences may also be the result of loose mix aging. Plant Mix 157 was aged 155 days from the day of sampling in an uncontrolled climate storage, and as a result, it may have observed the same effect of the zero-, two-, and four-hr 150° C laboratory loose mix aging specimens. Current investigation of laboratory-produced and plant-produced I-FIT testing is not sufficient to suggest whether the differences in results are due to production differences or loose mix aging differences. However, it is likely a combination of both. Consequently, it is recommended to test all plant mixes on the same time frame, so as to prevent differences in I-FIT results from varying loose mix aging.

Aging conclusions presented in Sections 4.3 and 4.4 may have significant impact on industry. Aging of compacted specimens, with slow decreases in FI, is not preventable and will happen over long periods of time. Certain mixes are likely more susceptible to aging, and it may be possible to develop an aging index to quantify a mixture's increased cracking potential over time.

Comparing aging of compacted specimens in Section 4.3 with loose mix aging in Section 4.4, it becomes evident that I-FIT results are much more sensitive to loose mix aging. This may have serious impacts on industry, since long-term aging of compacted pavement is inevitable, but loose mix aging can be controlled and limited. Contractors may be able to maximize field FI results by limiting silo storage and transport time of hot loose mixes.

Conclusions presented in Section 4.4 likely provide reasoning for the differences in plant mix FI and field core FI values. Field cores are subject to variable and unknown silo storage and transport time, which may have significantly affected I-FIT results. Additionally, each plant mix was subjected to different storage aging times, likely disproportionately affecting each plant mix. To summarize, field loose mix aging is likely disproportionate from section to section, plant mix storage aging is certainly disproportionate from mix to mix, and the comparison of field core and plant mix I-FIT results is likely conducted with disproportionate loose mix aging between the two. This explanation is likely the cause for differing I-FIT results between plant mix and field cores presented in Table 3.3.

4.5. Application of Mix-Applied Rejuvenation to Field Samples

With an understanding of the effect of rejuvenation and aging on I-FIT results, an investigation of rejuvenation more representative of field conditions is conducted. Rejuvenation of field cores will provide insight that is much more representative of field conditions than using plant or laboratory mix. Additionally, it mimics hot-in-place recycling even more closely than previous sections. This section directly investigates the effects of several rejuvenator dosages on actual field conditions in the state of Illinois.

Several facets of rejuvenation are investigated on field cores from various projects in Illinois. Questions were raised in Sections 4.1–4.2 over whether or not maintaining compaction effort or density is the more effective method of mix-applied rejuvenation. Both methods are attempted, and the preferred method is investigated and confirmed.

Field cores were obtained for mixes in Table 2.1, and analyzed in a similar fashion as the plant and laboratory mixes. Surface mix was isolated from the remainder of the field core

and brought to mixing temperature (160° C). Hydrolene H90T was applied and mixed, and the cores were recompacted.

Initial testing of a brittle mixture, Mix 338, placed at Harrison Street in Joliet, Illinois, provided some interesting conclusions. When the design compaction effort (N50) is applied, normal dosages of rejuvenator (i.e., 10% by binder weight) are not effective. Sans rejuvenation, field cores record a thickness corrected FI of 2.2. With a 10% rejuvenator dosage and design gyrations applied (N50), the rejuvenated FI does not increase and remains low at 1.8. This indicates that when rejuvenator is added and design compaction is maintained, the increase in density can negate the intended increase in flexibility. This is evidenced further in the study on air voids in Section 3.5, which suggests that decreases in air voids (in this case, rejuvenator filling in void space) correlate with decreases in the FI.

Mix 338, with N50 design gyrations, was rejuvenated at 10%, 20%, and 30% doses. Higher dosages were employed because of the ineffectiveness of a 10% dosage at design gyrations. Figure 4.12 presents the results of this investigation, with raw average data curves presented in Figure 4.13 and data presented in Table 4.3.

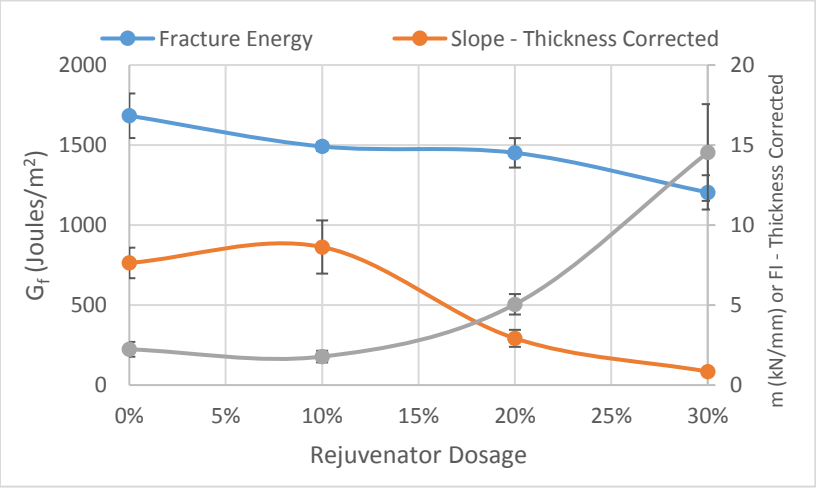


Figure 4.12 Field Core I-FIT and Rejuvenator Dosage: Design Compaction Effort

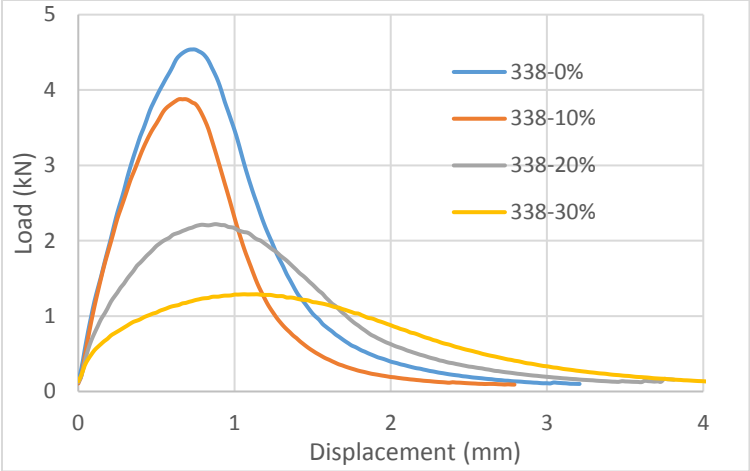


Figure 4.13 Field Core Rejuvenator Dosage I-FIT Curves: Design Compaction Effort

Table 4.3 Field Core I-FIT Parameters for Constant Compaction Effort Rejuvenation

Rejuvenator Dosage (%)	G_f (Joules/m²)	Slope (kN/mm) Thickness Corrected	FI Thickness Corrected
0	1683	7.6	2.2
10	1491	8.6	1.8
20	1451	2.9	5.0
30	1204	0.8	14.5

A consistent decrease of fracture energy occurs with increased rejuvenator dosage. Slope decreases do not occur until high levels of rejuvenation, leading to the increases in FI at high dosages. When design compaction is maintained, only extremely high levels of rejuvenator dosage are effective. Please note that non-rejuvenated FI values may be slightly lower than those presented in Table 3.3, due to storage aging.

At these extremely high levels of rejuvenation, the N-design is likely improper. The N-design gyration level is obtained for a certain liquid binder content (i.e., 6%), but adding 30% liquid rejuvenator by binder weight can increase the liquid content to almost 8%. As a result, an improper design is created, and applying the design levels of gyrations creates

excessive bleeding in the specimens and evident design flaws. Rejuvenator dosages of 30% by binder weight are not realistic.

It is likely that filling in voids with rejuvenator, as is the case when applying a constant compaction force, is not as effective as rejuvenation when maintaining a constant density, as supported by Sections 4.1–4.2. Rejuvenation of plant mixes in Section 4.1 maintained constant density and was relatively more effective than rejuvenation of laboratory mixes in Section 4.2, which employed an increase in density. Investigation of field core rejuvenation provides further evidence that maintaining density while adding rejuvenator to a standard design produces better flexibility increases and more appropriate designs.

Another recycled mix, Mix 185(N07), with high ABR content and details provided in Table 2.1, was used to investigate the effect of mix-applied rejuvenation on field cores while maintaining constant density. Again, please note that non-rejuvenated FI values may differ from those initially presented in Table 3.3 due to storage aging.

Densities of non-rejuvenated compacted field cores were measured, and data were subsequently used to control the density of rejuvenated specimens. After compaction, there were no visible issues in the specimens, as opposed to a constant compaction effort, where bleeding was immediately visible. Lower, more realistic rejuvenator dosages were investigated. Trends for rejuvenator dosages, in addition to standard design, while maintaining density, are presented in Figure 4.14, along with raw average data curves in Figure 4.15.

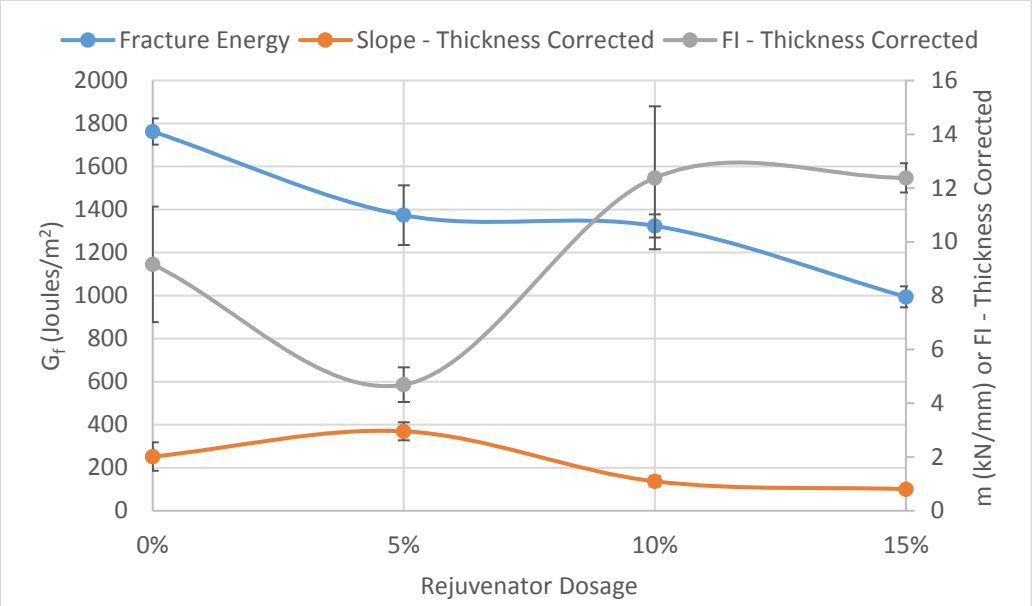


Figure 4.14 Field Core I-FIT and Rejuvenator Dosage: Constant Density

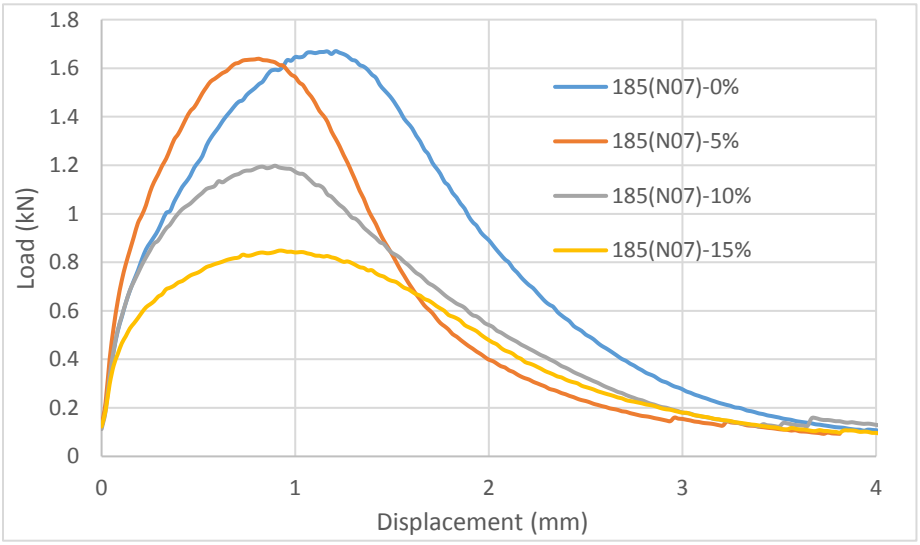


Figure 4.15 Field Core Rejuvenator Dosage I-FIT Curves: Constant Density

Please note that peak loads are lower than typical tests, since thinner field specimens are utilized. Thickness corrections from Section 3.4 are employed for the slope and FI. Again, a consistent decrease in fracture energy with increased rejuvenator dosage was observed. At a 5% dosage, an increase in slope, and thus a decrease in FI from the non-rejuvenated specimens was noted. It is likely that the reheating process introduced accelerated aging of the material, leading to the increase in slope, which should be negated by the rejuvenator.

In this case, however, a 5% dosage was not enough to overcome this loss in flexibility due to reheating the material.

A 10% dosage, on the other hand, successfully increases the FI by approximately 35%. Decreases in slope successfully increase the FI, despite fracture energy continuing to decrease with increased dosage. Interestingly, the 15% rejuvenated specimen did not experience an additional increase in FI from the values when 10% dosage was used, since decreases in fracture energy and slope were proportional. Data is presented in Table 4.4.

Table 4.4 Field Core IFIT Parameters for Constant Density Rejuvenation

Rejuvenator Dosage (%)	G_f (Joules/m^2)	Slope (kN/mm) Thickness Corrected	FI Thickness Corrected
0	1763	2.02	9.2
5	1374	2.96	4.7
10	1324	1.10	12.4
15	994	0.80	12.4

Maintaining constant density is more effective than maintaining the compaction effort. The FI increased by 35% with a rejuvenator dosage of 10%, whereas rejuvenation with a constant compaction effort and 10% dosage accomplishes nothing. Increasing FI while maintaining constant compaction effort is only possible at unreasonable doses, while effective FI increases can be observed at reasonable dosages if density is maintained. Unfortunately, no linear relationship exists between rejuvenator dosage and FI, as experienced in Section 4.1. However, the effect of reheating materials to mixing temperature is evident. Recall the low FI observed in Section 4.1 for material heated to mixing temperature at a 0% dosage (FI=0). In Section 4.1, 5% dosages experienced an increase in FI from 0% dosages, but they were only brought to near the FI value recorded

for standard plant mix compaction methods (FI=3.5), a method which does not involve heating the mix to 160° C. Similarly, 5% dosages of reheated field cores fail to achieve FI increases when compared with unaltered field cores. Evidence suggests that reheating asphalt mixtures to mixing temperature, a process encountered in HIR, significantly decreases FI and needs to be mitigated by rejuvenation.

Despite initial decreases in FI due to reheating, certain reasonable levels of rejuvenator can increase the FI if density is maintained. A 10% dosage of rejuvenator was shown to overcome the reheating effect and produce an FI increase of 35%.

4.6. Rutting Resistance of Rejuvenated Field Samples

The current understanding of asphalt materials suggests a trade-off between cracking resistance and rutting resistance. At low temperatures, asphalt materials that are too stiff are prone to cracking. At high temperatures, asphalt materials that are too soft are prone to rutting. Balanced mix design is the concept of designing mixes against both modes of material surface failure. The extent to which each mode of failure must be designed against is dependent on the climate in which the material is placed. The I-FIT is ideal for quantifying the cracking resistance of an asphalt mixture, while the Hamburg Wheel Tracking Test is ideal for quantifying the rutting resistance of an asphalt mixture.

Mix-applied rejuvenation has been shown to successfully increase the FI. This rejuvenation method, which softens the mix, may be beneficial to cracking resistance, but the concepts of balanced mix design suggest that it may be detrimental to rutting resistance. The effect of mix-applied rejuvenation on rutting resistance must therefore be investigated.

Field cores were utilized in this investigation to more closely represent field conditions. Field surface mix was isolated from their cores, melted, rejuvenated, and recompacted. This section employs surface Mix 185(N08), with details provided in Table 2.1. This surface mix is the same as Mix 185(N07), employed in Section 4.5, in all but virgin binder grade. Rejuvenator dosages investigated are 5%, 10%, and 20%.

AASHTO T-324 *(1)* is employed to evaluate the rutting resistance of rejuvenated field samples. The Hamburg Wheel Tracker runs a steel wheel, weighing 0.7 kN, repeatedly back and forth over the specimens with geometry presented in Figure 4.16. Testing continues until 20,000 passes or a maximum deformation of 20 mm, whichever is encountered first. Due to material constraints, only one test is performed for each rejuvenator level. For reference, IDOT defines failure at a minimum amount of cycles to achieve a 12.5 mm rut depth.

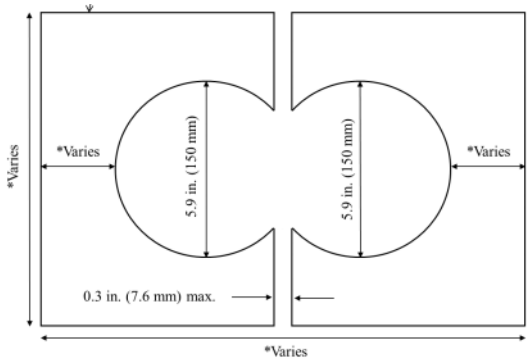


Figure 4.16 Hamburg Wheel Track Test Apparatus

Results for Hamburg Wheel Tracking of rejuvenated specimens are presented in Figure 4.17. Results are as expected. Increased rejuvenator dosage softens the material and decreases the rutting resistance. Drastic failure is immediately noticeable for the 20% rejuvenated specimens. 5% and 10% rejuvenated specimens have acceptable rutting

performance, depending on the requirements applied, with the 5% specimens outperforming the 10% specimens.

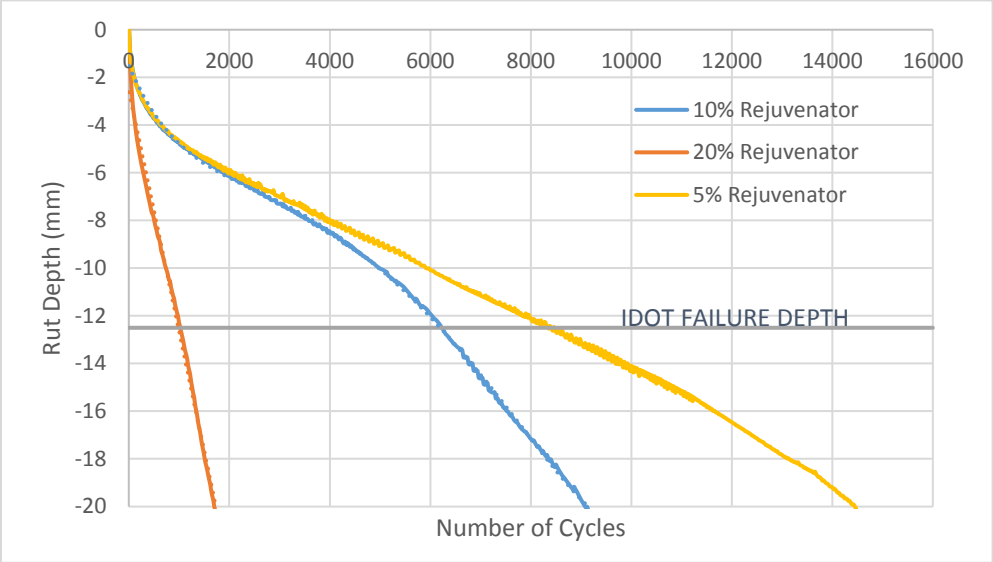


Figure 4.17 Rejuvenated Field Core Hamburg Results

Figure 4.17 validates the concept of balanced mix design applying directly to mix-applied rejuvenation. With increased rejuvenator dosage, FI and cracking resistance increased, but observe decreased performance in the Hamburg Wheel rutting resistance. When rejuvenating field sections, rejuvenator dosages must be low enough to avoid potential rutting.

4.7. Optimization of Mix-Applied Rejuvenator Dosage and FI

Investigation into mix-applied rejuvenation rutting resistance allows us to determine the exact rejuvenator dosage that will result in rutting failure. Due to the tradeoff that exists between rutting resistance and cracking resistance, a dosage just below rutting failure (maximum allowable dosage) will result in the highest attainable FI. This concept allows

for the optimization of rejuvenator dosage in order to maximize flexibility while maintaining rutting performance.

Rutting failure criteria is climate dependent, with more rut resistant mixes needed in hotter areas. Therefore, an analysis of field cores allows for the development of a method of rejuvenation dosage optimization dependent on climate, mix design, and the type of rejuvenator used.

The requirements for Hamburg rutting failure vary from state to state, and are climate dependent. For simplicity, the IDOT criteria are utilized in this optimization *(35)*. It is certainly possible for other criteria to be implemented in a similar manner.

Applying state rutting failure criteria, and understanding trends presented throughout Chapter 4, the optimal dosage of rejuvenator can be determined. Chapter 4 investigations suggest that typically, in terms of the FI, the more rejuvenator added the better. However, Section 4.6 indicates that there is a point at which excessive rejuvenator dosage will cause rutting failure. With this knowledge, the maximum allowable rejuvenator dosage that ensures rutting performance and maximizes flexibility increase can be identified. Of course, with test variability, certain reliability factors must be applied.

IDOT defines rutting failure at a 12.5mm Hamburg rut depth. They also prescribe the minimum amount of passes allowed to reach this failure depth. The minimum amount of passes is higher in hotter climates (denoted as high temperature performance grades), in order to guarantee more rut resistant designs at higher temperatures. Please see Table 4.5 for these values.

Table 4.5 IDOT Rutting Criteria

PG Grade	Number of Passes
PG 58-xx (or lower)	5,000
PG 64-xx	7,500
PG 70-xx	15,000
PG 76-xx (or higher)	20,000

To gain a better understanding of rejuvenations effect on rutting failure criteria, Table 4.6 and Figure 4.18 are presented. This table and figure display the Hamburg cycles necessary to reach a 12.5 mm failure depth, dependent on the rejuvenator dosage. A high degree of linearity is found between the cycles to 12.5 mm and the rejuvenator dosage. This proves particularly useful in optimizing the rejuvenator dosage.

Table 4.6 Rejuvenator Dosage and Passes to Failure

Rejuvenator Dosage (%)	Passes to 12.5 mm
5	8340
10	**6230**
20	1025

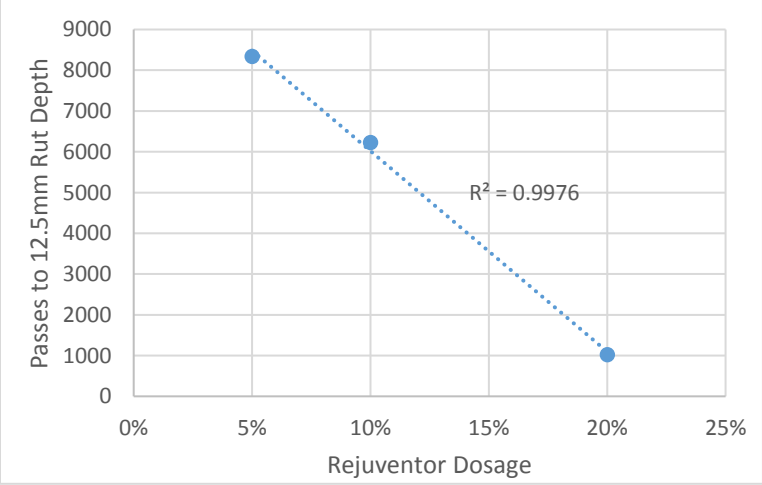


Figure 4.18 Rejuvenator Dosage and Passes to Failure

The high temperature grade for the climate must be obtained in order to determine the minimum allowable passes. LTTPBind software *(36)* maps Superpave PG grades across the United States and can be utilized to obtain the high temperature grade that corresponds with the given climate. Mix 185(N08) is placed near Joliet, Illinois, where the high pavement temperature is 54.1° C. PG 58-22 can be used with 98.9% reliability, and is therefore the proper binder grade.

By IDOT standards, the high temperature grade of 58 or lower corresponds to 5,000 minimum allowable passes to 12.5 mm rut depth. Using these criteria, the maximum allowable rejuvenator dosage can be obtained using Figure 4.19. The dosage would be slightly reduced when 85% reliability is applied.

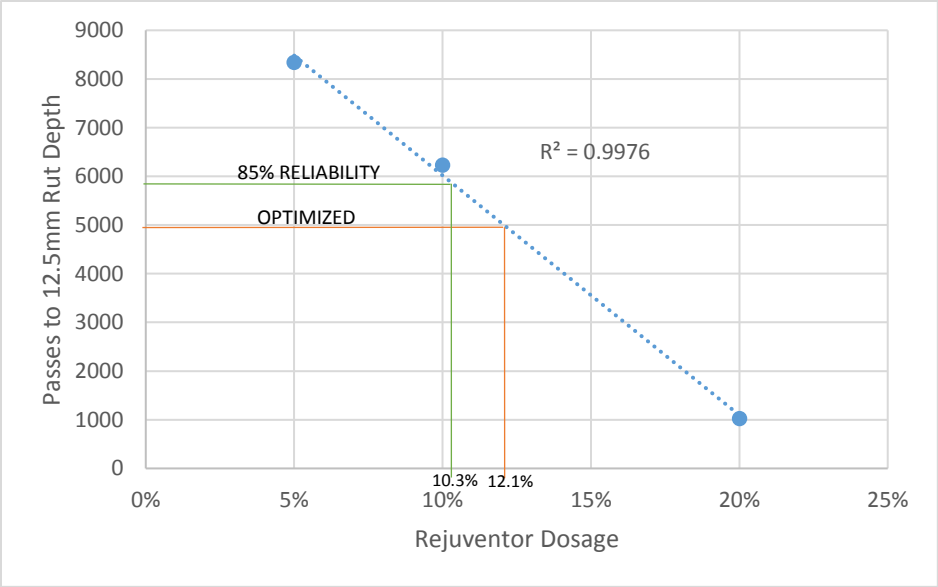


Figure 4.19 Rejuvenator Dosage Optimization Projection

Using the linear regression of rutting failure, a maximum allowable rejuvenator dosage of 12.1% is determined. This dosage would have a significant risk of rutting failure, since it is designed exactly for failure criteria, considering rutting performance variance exists. To combat this, an 85% reliability is applied to the minimum allowable passes to failure, and

then applied to the linear regression. This results in a maximum allowable rejuvenator dosage of 10.1%. The maximum allowable rejuvenator dosage is rounded down to 10% for simplicity.

- **Optimized Rejuvenator Dosage: 10%**

Applying this dosage to Mix 185(N08) and analyzing via the I-FIT method, an optimized increase in FI is presented in Table 4.7.

Table 4.7 Optimized I-FIT Results

	N08-0%		N08-10%	
	Average	COV (%)	Average	COV (%)
Fracture Energy	1586	5	**717**	12
Slope (Thickness Adjusted)	1.54	9	0.52	31
Flexibility Index (Thickness Adjusted)	10.4	13	14.9	32

We observe a 44% increase in FI as a result of the optimal dosage, which has been shown to pass rutting criteria (Table 4.6). However, this increase in FI is entirely the result of a decrease in slope. Unfortunately, decreases in fracture energy are drastic and may prove problematic. For the case tested, a 10% rejuvenator dosage cuts the fracture energy by more than half, to an atypically low level of 717 J/m^2. Typically, SCB fracture energy for an AC mixture is not below 1200 J/m^2. In some cases, a minimum fracture energy criterion may be identified.

As previously stated, the process of mix-applied rejuvenation to field cores closely resembles HIR, a rehabilitation method in which all activities are done on site. The pavement is heated to adequate mixing temperature in order to dissolve surface distresses.

The loose material is scarified, rejuvenator and/or additional binder is applied, and loose material is mixed. The material is then followed by a roller and recompacted. While previous laboratory procedures do not directly mimic HIR, the processes are similar, and results experienced in the lab can be expected to be similar to results in the field for HIR.

Due to high similarities between investigations of Sections 4.5–4.6 and HIR, the method outlined below ideally can be applied to optimize flexibly for HIR projects. This general method can be applied to any surface mix, any rejuvenator, any climate, and any set of failure criteria. The simple steps are as follows.

1. Obtain the necessary amount of field cores, which will vary with surface layer thicknesses.
2. Conduct rejuvenated Hamburg tests at 5%, 10%, and 15%, or other dosages if the engineer's judgment suggests otherwise.
3. Graph cycles to failure vs. rejuvenator dosage (using a validated failure criteria). If not linear, fit a smooth curve.
4. Using a validated set of failure criteria, determine the minimum number of Hamburg Wheel Track cycles to failure for the project's climate.
5. Apply a reliability factor, determined by the engineer, to the minimum allowable number of cycles.
6. Using the graph obtained in Step 3, project the optimal rejuvenator dosage, dependent on the minimum allowable number of cycles with a reliability factor applied. Round down to the nearest percentage point for simplicity and additional reliability.

7. Rejuvenate mix to the optimal rejuvenator dosage and test via the I-FIT method. Compare results with unaltered field cores, and report the flexibility increase.
8. Check the fracture energy of the optimized dosage. If below a reasonable minimum as defined by the engineer, test lower rejuvenator dosages and use the minimum fracture energy as a criterion to obtain a new optimal rejuvenator dosage.
9. Apply the optimal rejuvenator dosage in the field, so as to maximize the cracking resistance of the surface while maintaining proper rutting resistance.

This simplified and general method may prove to be useful for contractors who practice HIR. However, it must be noted that laboratory procedures will not mimic field conditions perfectly. Additionally, the outline is general and needs to be taken within the context of each project. Differences in mix designs, rejuvenators, climates, and appropriate failure criteria must be weighed when determining the proper approach for optimizing flexibility for HIR projects.

Lastly, it may be more beneficial to apply both rejuvenator and new virgin binder, so as to increase FI and maintain acceptable fracture energy. HIR construction procedures result in severe binder loss, and therefore it may be more appropriate to utilize this optimization method using dosages of both rejuvenator and new binder.

5. Summary, Conclusions, and Recommendations

5.1. Summary

The Illinois Flexibility Index Test (I-FIT) method is found to be an effective procedure for characterizing the flexibility and cracking resistance of asphalt mixtures, as well as identifying potential brittleness mitigation strategies. The I-FIT method was thoroughly investigated, and impact factors for the test were analyzed, including mixture design (more importantly, binder softening), thickness of specimens, air void content, and mix-applied rejuvenation. Mix-applied rejuvenation was performed on plant AC mix, laboratory-produced AC mix, and field cores. Additionally, the effect of aging on I-FIT results was investigated. Extensive investigation into multiple mediums allowed for development of ideal rejuvenation practices. High similarities between mix-applied rejuvenation and hot-in-place recycling may allow the outcome of this study to be applied to the field practice of HIR.

5.2. Findings and Conclusions

I-FIT testing of several high ABR designs in the state of Illinois provided insight into the effect of recycled materials on the FI. The following are findings of this study:

- Higher ABR mixtures were shown to have lower FIs, which was primarily the result of their stiffer asphalt binder. Recycled asphalt shingles were observed to decrease the FI more so than recycled asphalt pavement.
- Binder softening was shown to be a successful strategy of increasing the FI. Binder softening can be a very successful method of increasing FI for asphalt mixes with ABR solely from RAP, or when RAS levels are moderate. Asphalt mixtures with high

RAS content, however, struggle to meet acceptable FI values despite binder softening.

- Field core FIs were higher than their plant mix counterparts. Differences in specimen thicknesses was the main factor in FI differences. Additionally, aging likely affected plant mix and field cores disproportionally. Plant mix was stored loose whereas field cores were compacted after production and variable loose mix aging, and both were tested on different time frames. Differences in compaction method also may have led to higher FIs in the field.
- Investigation into mix-applied rejuvenation of laboratory-produced specimens allowed for analysis of different volumetric rejuvenation designs. Analysis of a design with rejuvenator as a replacement for certain levels of binder showed that the rejuvenator does in fact have a softening effect, and it is not simply the additional liquid causing the increase in FI. Adding binder to a standard design was also found to increase FI, while maintaining more acceptable levels of fracture energy when compared with rejuvenation. However, rejuvenator in addition to a standard design was found to be the most effective method of increasing FI values. Maintaining density with rejuvenation application, as opposed to maintaining compaction effort, was found to be the most effective design for increasing flexibility.
- Aging of compacted mixtures found that rejuvenated mixes aged similarly to their non-rejuvenated counterparts. Additionally, compacted rejuvenated specimen FI was shown to decrease to its non-rejuvenated FI only after long-term aging.

- Mix-applied rejuvenation to field cores closely resembles the practice of hot-in-place recycling. Applying constant design compaction effort for rejuvenated specimens was shown to be an improper method of rejuvenation design. Rejuvenation in addition to standard design, while maintaining density, was confirmed to be the most effective method of increasing the FI.
- Reasonable rejuvenator dosages achieve increases in field core FIs. However, reheating field specimens decreases the FI after recompaction, a decrease that may not be able to be overcome by a low rejuvenator dosage. Loss of flexibility due to reheating is a likely cause for cracking failure in HIR projects.
- Rejuvenation levels necessary to overcome FI decreases may push the fracture energy to unacceptably low levels. This suggests that the FI may not be a proper metric for materials with very low fracture energy. Lastly, rutting resistance of rejuvenated field cores was investigated and shown to be acceptable for certain levels of rejuvenation.

The following conclusions are drawn in this study:

- The FI is shown to increase with decreasing thickness. The effect of thickness on fracture energy is negligible, but a linear decrease in slope with decreasing thickness is observed. This linear relationship manifests itself in a linear relationship between FI and specimen thickness. The linear relationship between FI and specimen thickness allows for a simple normalization to successfully correct for thickness differences. This correction is successfully applied to thinner field core specimens.

- Loose AC mix aging significantly affects the FI. Longer loose mix aging times correspond to a change in fracture curve shape similar to SHRP-recommended aging of compacted specimens, but more rapid. With increased loose mix aging time, I-FIT curve shape becomes more brittle, while maintaining similar fracture energy.
- The FI is shown to increase with increasing air voids. The fracture energy and slope both decrease with increasing air voids, but the slope decreases more relatively rapidly, leading to an increase in FI with increased air voids. Based on I-FIT parameter trends with air void content in plant AC mixtures, a correction for air voids was developed. This correction is successful for plant AC mixtures, but may not be applied to field core FI values.
- Mix-applied rejuvenation is shown to be a successful method of increasing the FI. Application of Hydrolene H90T, a petroleum-based softening agent, to plant mix while maintaining density successfully increased the FI. Both fracture energy and slope decrease with increased rejuvenator dosage, but slope decreases were more relatively rapid, leading to an increase in FI.
- It is possible to optimize rejuvenator dosage based on a multitude of factors, including rutting resistance and fracture energy. This method may prove particularly useful to contractors involved in hot-in-place recycling, allowing them to minimize the cracking potential of their projects.

5.3. Recommendations

Investigations in this thesis suggest that the I-FIT method is ideal for evaluating excessive brittleness of recycled asphalt mixtures. Data suggest that binder softening for recycled asphalt mixes should be continued. Additionally, it is recommended to limit RAS usage, so as to effectively limit reductions in the FI.

Applying a thickness correction factor is recommended on all field specimens with less than 50 mm thickness. The correction can also be employed on laboratory-produced specimens; however, it is recommended to simply produce specimens to proper thicknesses.

An air void correction factor can be used successfully for plant and laboratory-produced mixes that fall reasonably outside air void specification. However, this correction is not recommended for use on field cores.

Investigation into the effect of aging on I-FIT results found it to be a critical parameter. However, investigations were limited and far from comprehensive. A full-scale investigation into the effect of aging on flexibility index parameters is recommended, with the possible end result of creating an I-FIT aging index to properly characterize the potential for FI decreases as a result of aging.

I-FIT results were found to be more sensitive to loose mix aging than aging of compacted specimens. It is therefore likely that limiting loose mix aging, in the form of silo storage and transport time, will maximize field FIs. It is recommended that contractors limit loose mix aging time, so as to effectively increase the initial FI of field sections.

Investigation into mix-applied rejuvenation, which provides insight into hot-in-place recycling, found it to be a successful method of increasing the FI. It is recommended that HIR contractors consider implementing the general method of optimizing rejuvenator dosage as a measure to limit cracking failure of HIR projects..

Lastly, investigations of the I-FIT method found that FI values can increase despite decreased fracture energy. In certain situations, a lower post-peak slope may outweigh a lower fracture energy. Consequently, it is possible for the FI to present good values while the fracture energy is unacceptably low. Therefore, it is recommended to implement a minimum fracture energy requirement alongside the flexibility index, so as to properly design against materials that will crack with little energy applied, despite ductile fracture curves.

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Appendix A – Job Mix Formulas

Details for each asphalt mixture tested are presented in job mix formulas provided by contractors, organized as follows.

A.1: Mix 157M……81

A.2: Mix 156M……82

A.3: Mix 140M……83

A.4: Mix 159M(Y02)……84

A.5: Mix 185M(N08)……85

A.6: Mix 185M(N07)……86

A.7: Mix 159M(Y04)……87

A.8: Mix 177M……88

A.9: Mix 137M……89

A.10: Mix 338K……90

A.11: Mix 138Z……91

A.12: Mix 306K……92

A.13: Mix 163M (N07)……93

A.1: Mix 157M

Granted SB 5.14

IDOT Lab Verification No.: 48BITVS89 Ver. 11.01-07.07.14 DATE: 09/19/14

Producer Number & Name → 5116-06 | Sandeno East | Hazel Crest ← Plant Location

Material Code Number → 19524R HMA SC N70 D REC 9.5mm

81BIT157M Y03

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	RAS #2	RAP #1	ASPHALT
Size				032CM16	028FM20	027FM02		004MF01			017FM98	017FM0400	10125
Source (PROD #				50312-04	50312-04	52600-05		50312-04			6616-06	50315-12	Seneca
(NAME)				Hanson	Hanson	Moose Lk		Hanson			Southwind	Sandeno East	1757-05
(LOC)				Thornton	Thornton	Niles, MI		Thornton			Thornton	Hazel Crest	Lemont
(ADD. INFO)													PG 58-28
									0.0	0.0	25.0	4.5	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 58-28
	0.0	0.0	0.0	62.0	13.0	10.0	0.0	1.0	0.0	0.0	4.0	10.0	100.0
	Mixture Blend:												Totals:
	0.0	0.0	0.0	58.4	12.2	9.4	0.0	0.9	0.0	0.0	5.0	9.9	100.0

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	RAS #2	RAP #1	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	100.0	100.0	100.0	95.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97	90-100
No.4 (4.75mm)	100.0	100.0	100.0	29.0	98.0	97.0	100.0	100.0	100.0	100.0	96.0	74.0	53	32-69
No.8 (2.36mm)	100.0	100.0	100.0	7.0	81.0	87.0	100.0	100.0	100.0	100.0	85.0	54.0	33	32-52
No.16 (1.18mm)	100.0	100.0	100.0	5.0	50.0	77.0	100.0	100.0	100.0	100.0	67.0	40.0	25	10-32
No.30 (600µm)	100.0	100.0	100.0	4.0	31.0	57.0	100.0	100.0	100.0	100.0	50.0	30.0	18	
No.50 (300µm)	100.0	100.0	100.0	4.0	16.0	23.0	100.0	100.0	100.0	100.0	40.0	19.0	12	4-15
No.100 (150µm)	100.0	100.0	100.0	3.0	10.0	3.0	100.0	95.0	100.0	100.0	35.0	12.0	7	3-10
No.200(75µm)	100.0	100.0	100.0	3.0	5.3	1.1	100.0	90.0	100.0	100.0	26.5	8.6	5.5	4-6
Bulk Sp Gr	1.000	1.000	1.000	2.669	2.676	2.591	1.000	2.900	1.000	1.000	2.500	2.660	2.656	Dust/AB
Absorption, %	1.00	1.00	1.00	1.70	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.42	Ratio
												SP GR AB	1.031	0.94

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int. 7

	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.3	2.140	2.519	15.1	23.7	36.5	8.66	4.17	1.19
MIX 2	5.8	2.155	2.499	13.8	23.6	41.6	9.80	4.69	1.18
MIX 3	6.3	2.158	2.478	12.9	23.9	46.9	10.95	5.23	1.14
MIX 4	6.8	2.165	2.461	12.0	24.0	49.9	12.01	5.72	1.16

DATA for N-des. 70

		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.3	2.378	2.519	5.6	15.2	63.2	9.62	4.17	2.740	1.19
MIX 2	5.8	2.397	2.499	4.1	15.0	72.8	10.90	4.69	2.739	1.18
MIX 3	6.3	2.408	2.478	2.8	15.1	81.3	12.22	5.23	2.736	1.14
MIX 4	6.8	2.419	2.461	1.7	15.1	88.7	13.42	5.72	2.738	1.16

Hamburg Wheel Information	
Sample No. Passes	10000
Sample Wheel Depth	2.10

TSR Information	
Conditioned	124.9
Unconditioned	141.2
TSR	0.88
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes

GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	5.83			Target								
70	5.8	2.398	2.498	4.0	15.0	73.3	2.739	2.656	0.88	1.70	4.13	29.2

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED 1 HOURS @ 295

81BIT157M

Lab Preparing Design PP

Designing Lab Mix# TPN7030%

Designing Lab Name D Con

Tested by : _____ Verified by: _____

Reviewed by : _____ Final Approval : _____

A.2: Mix 156M

Crushed N3 Surf

IDOT Lab Verification No.: 48BITVS84 Ver. 11.01-07.07.14 DATE: 09/15/14

Producer Number & Name: 5116-06 Sandeno East Hazel Crest <— Plant Location

Material Code Number: 19524R HMA SC N70 D REC 9.5mm

81BIT156M Y03

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	RAS #2	RAP #1	ASPHALT
Size				032CM16	028FM20	027FM02		004MF01			017FM98	017FM0400	10127
Source (PROD #)				50312-04	50312-04	52600-06		50312-04			6816-06	50315-12	Seneca
(NAME)				Hanson	Hanson	Moose Lk		Hanson			Southwind	Sandeno East	1757-05
(LOC)				Thornton	Thornton	Niles, MI		Thornton			Thornton	Hazel Crest	Lemont
(ADD. INFO)													PG 64-22
									0.0	0.0	25.0	4.5	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 64-22
	0.0	0.0	0.0	65.0	15.0	12.0	0.0	1.0	0.0	0.0	2.0	5.0	100.0
	Mixture Blend:												Totals:
	0.0	0.0	0.0	61.3	14.2	11.3	0.0	0.9	0.0	0.0	2.5	4.9	100.0

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	RAS #2	RAP #1	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	100.0	100.0	100.0	95.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97	90-100
No.4 (4.75mm)	100.0	100.0	100.0	29.0	98.0	97.0	100.0	100.0	100.0	100.0	55.0	74.0	52	32-69
No.8 (2.36mm)	100.0	100.0	100.0	7.0	81.0	87.0	100.0	100.0	100.0	100.0	85.0	54.0	33	32-52
No.16 (1.18mm)	100.0	100.0	100.0	5.0	50.0	77.0	100.0	100.0	100.0	100.0	67.0	40.0	24	10-32
No.30 (600µm)	100.0	100.0	100.0	4.0	31.0	57.0	100.0	100.0	100.0	100.0	50.0	30.0	18	
No.50 (300µm)	100.0	100.0	100.0	4.0	18.0	23.0	100.0	100.0	100.0	100.0	40.0	19.0	11	4-15
No.100 (150µm)	100.0	100.0	100.0	3.0	10.0	3.0	100.0	95.0	100.0	100.0	35.0	12.0	6	3-10
No.200(75µm)	100.0	100.0	100.0	3.0	5.3	1.1	100.0	90.0	100.0	100.0	26.5	8.6	4.7	4-6
Bulk Sp Gr	1.000	1.000	1.000	2.669	2.676	2.691	1.000	2.900	1.000	1.000	2.500	2.660	2.659	Dust/AB
Absorption, %	1.00	1.00	1.00	1.70	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.45	Ratio
												SP GR AB	1.031	0.83

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int. 7

	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.2	2.129	2.512	15.3	24.1	36.7	8.84	4.28	0.97
MIX 2	5.7	2.148	2.494	13.9	23.8	41.8	9.96	4.78	0.98
MIX 3	6.2	2.137	2.478	13.8	24.6	44.1	10.86	5.24	1.02
MIX 4	6.7	2.127	2.460	13.5	25.4	46.5	11.82	5.73	1.04

DATA for N-des. 70

		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.2	2.373	2.512	5.5	15.4	64.1	9.85	4.28	2.727	0.97
MIX 2	5.7	2.395	2.494	4.0	15.1	73.6	11.10	4.78	2.728	0.98
MIX 3	6.2	2.410	2.478	2.7	15.0	81.7	12.25	5.24	2.731	1.02
MIX 4	6.7	2.420	2.460	1.6	15.1	89.2	13.45	5.73	2.732	1.04

Hamburg Wheel Infomation	
Sample No. Passes	10000
Sample Wheel Depth	3.50

TSR Information	
Conditioned	129.2
Unconditioned	144.1
TSR	0.90
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes

GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	5.69			Target								
70	5.7	2.394	2.494	4.0	15.1	73.5	2.728	2.659	0.90	0.85	4.84	14.9

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED 1 HOURS @ 295

81BIT156M

Lab Preparing Design: PP

Designing Lab Mix#: TPN7015%

Designing Lab Name: D Con

Tested by: _____ Verified by: _____

Reviewed by: _____ Final Approval: _____

A.3: Mix 140M

C to L EB Surface

IDOT Lab Verification No.: 48BITVQ98 Ver. 10.00-04.15.13 DATE: 01/29/14

Producer Number & Name → 5116-05 | D Construction | Rockdale ← Plant Location

Material Code Number → 19524R | HMA N70 D REC SURF 9.5mm

81BIT140M

702

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	ASPHALT
Size	032CM16		038FM20	037FM02				004MF01	017CM1204	017FM98			10126
Source (PROD #)	51972-15		51972-15	50990-54				5116-05	5116-05	6616-01			1757-05
(NAME)	LaFarge		LaFarge	Kelly Co				D Const	D Const	Southwind			Seneca
(LOC)	Joliet		Joliet	Norway				Rockdale	Rockdale	Thornton			Lemont
(ADD. INFO)													PG 58-28
									4.8	25.0	0.0	0.0	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 58-28
	48.0	0.0	21.5	7.5	0.0	0.0	0.0	0.5	20.0	2.5	0.0	0.0	100.0
	Mixture Blend:												Totals:
	45.2	0.0	20.2	7.1	0.0	0.0	0.0	0.5	19.8	3.1	0.0	0.0	100.0

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	97.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	93.0	100.0	100.0	100.0	97	90-100
No.4 (4.75mm)	36.0	100.0	100.0	97.0	100.0	100.0	100.0	100.0	69.0	95.0	100.0	100.0	61	32-69
No.8 (2.36mm)	7.0	100.0	80.0	83.0	100.0	100.0	100.0	100.0	37.0	85.0	100.0	100.0	37	32-52
No.16 (1.18mm)	5.0	100.0	58.0	67.0	100.0	100.0	100.0	100.0	28.0	67.0	100.0	100.0	28	10-32
No.30 (600µm)	4.0	100.0	32.0	47.0	100.0	100.0	100.0	100.0	22.0	50.0	100.0	100.0	18	
No.50 (300µm)	4.0	100.0	25.0	20.0	100.0	100.0	100.0	95.0	16.0	40.0	100.0	100.0	13	4-15
No.100 (150µm)	4.0	100.0	11.0	6.0	100.0	100.0	100.0	90.0	11.0	35.0	100.0	100.0	8	3-10
No.200(75µm)	3.3	100.0	4.9	3.9	100.0	100.0	100.0	85.0	7.6	26.5	100.0	100.0	5.5	4-6
Bulk Sp Gr	2.659	1.000	2.716	2.589	1.000	1.000	1.000	2.900	2.660	2.500	1.000	1.000	2.664	Dust/AB
Absorption, %	1.80	1.00	0.90	1.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.26	Ratio
												SP GR AB	1.040	0.95

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int.	7								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.2	2.146	2.534	15.3	23.6	35.2	8.32	4.03	1.23
MIX 2	5.7	2.158	2.506	13.9	23.6	41.2	9.73	4.69	1.07
MIX 3	6.2	2.185	2.490	12.3	23.1	46.9	10.82	5.15	1.12
MIX 4	6.7	2.213	2.479	10.7	22.5	52.3	11.77	5.53	1.25

DATA for N-des.	70									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.2	2.373	2.534	6.4	15.6	59.2	9.20	4.03	2.751	1.23
MIX 2	5.7	2.396	2.506	4.4	15.2	71.1	10.81	4.69	2.739	1.07
MIX 3	6.2	2.416	2.490	3.0	14.9	80.1	11.96	5.15	2.743	1.12
MIX 4	6.7	2.428	2.479	2.1	15.0	86.2	12.91	5.53	2.752	1.25

Hamburg Wheel Information	
Sample No. Passes	20000
Sample Wheel Depth	-1.98

TSR Information	
Conditioned	152.6
Unconditioned	155.9
TSR	0.98
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes												
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	5.84			Target								
70	5.8	2.402	2.502	4.0	15.1	73.5	2.741	2.664	0.98	1.73	4.11	29.6

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED 1 HOURS @ 295

81BIT140M

Lab Preparing Design: PP

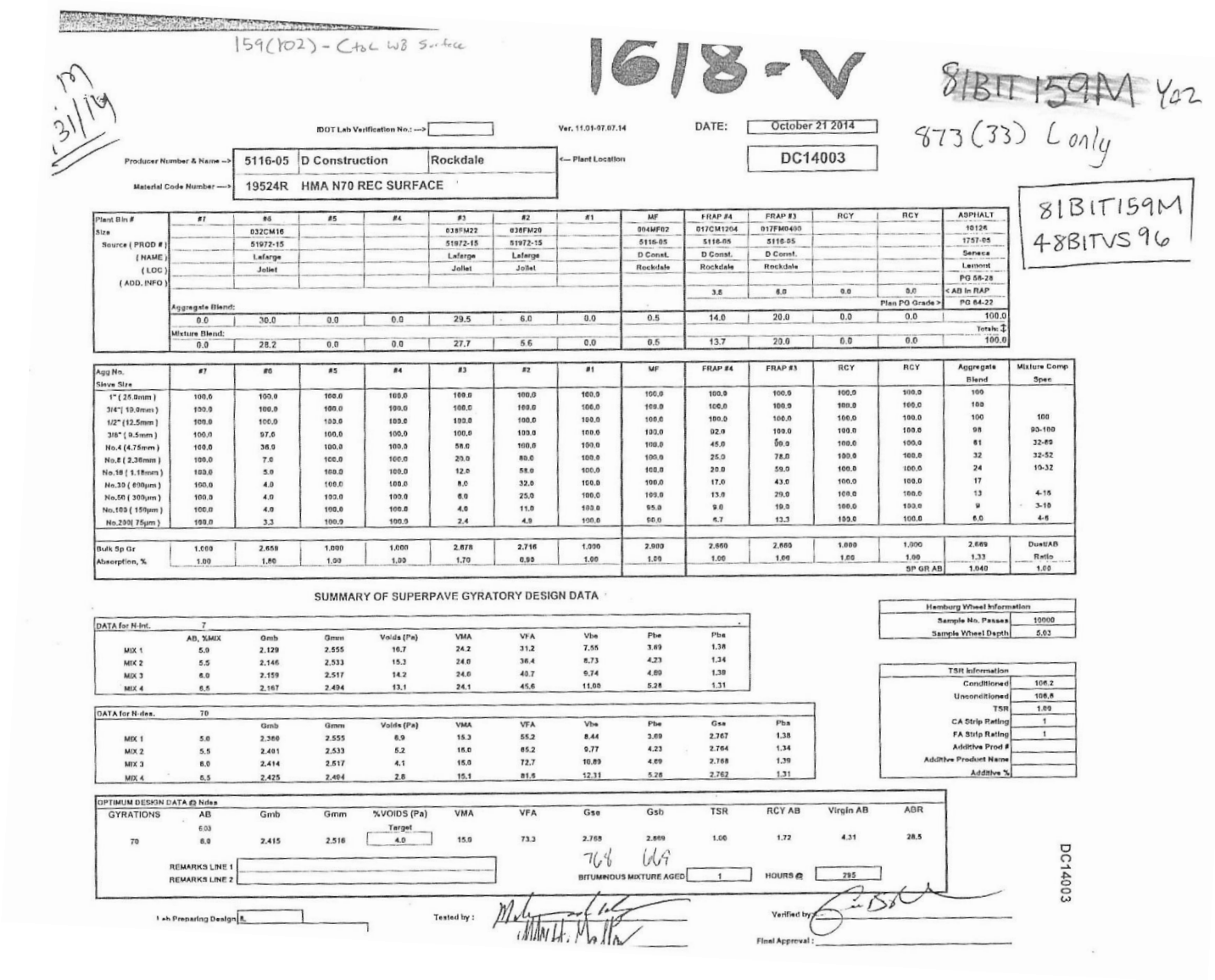
Designing Lab Mix #: 81BIT901M

Designing Lab Name: D Const

Tested by : _____ Verified by: _____

Reviewed by : _____ Final Approval : _____

A.4: Mix 159M (Y02)



159(Y02) - Ctac W8 Surface

1618-V

8IBIT 159M Y02

873(33) Only

8IBIT159M
48BITVS96

IDOT Lab Verification No.: ---> Ver. 11.01-07.07.14 DATE: October 21 2014

Producer Number & Name --> 5116-05 | D Construction | Rockdale <-- Plant Location

Material Code Number ---> 19524R HMA N70 REC SURFACE

DC14003

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	FRAP #3	RCY	RCY	ASPHALT
Size		032CM16			038FM22	038FM20		004MF02	017CM1204	017FM0400			10126
Source (PROD #)		51972-15			51972-15	51972-15		5116-05	5116-05	5116-05			1757-05
(NAME)		Lafarge			Lafarge	Lafarge		D Const.	D Const.	D Const.			Seneca
(LOC)		Joliet			Joliet	Joliet		Rockdale	Rockdale	Rockdale			Lamont
(ADD. INFO)													PG 58-28
									3.6	6.0	0.0	0.0	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 64-22
	0.0	30.0	0.0	0.0	29.5	6.0	0.0	0.5	14.0	20.0	0.0	0.0	100.0
	Mixture Blend:												Totals:
	0.0	28.2	0.0	0.0	27.7	5.6	0.0	0.5	13.7	20.0	0.0	0.0	100.0

Agg No. / Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	FRAP #3	RCY	RCY	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4" (19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	100.0	97.0	100.0	100.0	100.0	100.0	100.0	100.0	92.0	100.0	100.0	100.0	98	90-100
No.4 (4.75mm)	100.0	36.0	100.0	100.0	58.0	100.0	100.0	100.0	45.0	99.0	100.0	100.0	61	32-69
No.8 (2.36mm)	100.0	7.0	100.0	100.0	20.0	80.0	100.0	100.0	25.0	78.0	100.0	100.0	32	32-52
No.16 (1.18mm)	100.0	5.0	100.0	100.0	12.0	58.0	100.0	100.0	20.0	59.0	100.0	100.0	24	10-32
No.30 (600µm)	100.0	4.0	100.0	100.0	8.0	32.0	100.0	100.0	17.0	43.0	100.0	100.0	17	
No.50 (300µm)	100.0	4.0	100.0	100.0	6.0	25.0	100.0	100.0	13.0	29.0	100.0	100.0	13	4-15
No.100 (150µm)	100.0	4.0	100.0	100.0	4.0	11.0	100.0	95.0	9.0	19.0	100.0	100.0	9	3-10
No.200(75µm)	100.0	3.3	100.0	100.0	2.4	4.9	100.0	60.0	6.7	13.3	100.0	100.0	6.0	4-8
Bulk Sp Gr	1.000	2.658	1.000	1.000	2.678	2.716	1.000	2.900	2.660	2.660	1.000	1.000	2.669	Dust/AB
Absorption, %	1.00	1.80	1.00	1.00	1.70	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.33	Ratio
												SP GR AB	1.040	1.00

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-Int.	7								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.0	2.129	2.555	16.7	24.2	31.2	7.55	3.69	1.38
MIX 2	5.5	2.146	2.533	15.3	24.0	36.4	8.73	4.23	1.34
MIX 3	6.0	2.159	2.517	14.2	24.0	40.7	9.74	4.69	1.39
MIX 4	6.5	2.167	2.494	13.1	24.1	45.6	11.08	5.28	1.31

DATA for N-des.	70									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.0	2.360	2.555	8.9	15.3	55.2	8.44	3.69	2.767	1.38
MIX 2	5.5	2.401	2.533	5.2	15.0	65.2	9.77	4.23	2.764	1.34
MIX 3	6.0	2.414	2.517	4.1	15.0	72.7	10.89	4.69	2.768	1.39
MIX 4	6.5	2.425	2.494	2.8	15.1	81.5	12.31	5.28	2.762	1.31

OPTIMUM DESIGN DATA @ Ndes											
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	6.03			Target								
70	6.0	2.415	2.516	4.0	15.0	73.3	2.768	2.669	1.00	1.72	4.31	28.5

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED 1 HOURS @ 295

Hamburg Wheel Information

Sample No. Passes	10000
Sample Wheel Depth	5.03

TSR Information

Conditioned	106.2
Unconditioned	106.6
TSR	1.00
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

Lab Preparing Design: IL

Tested by:

Verified by:

Final Approval:

DC14003

A.5: Mix 185M (N08)

60N08 52-34

IDOT Lab Verification No.: ---> Ver. 11.10-12.08.14

DATE: 04/24/15

Sampled 8/6/15

60N07 52-28

Producer Number & Name -->	5116-05	D Construction	Rockdale	<-- Plant Location
Material Code Number -->	19524R	HMA SC N70 D REC 9.5mm		

BIT185M

N08

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	ASPHALT
Size	039CM13	039CM16	039FM20						017FM3800	017FM98			10136
Source (PROD #)	51433-02	51975-08	51953-01						5116-05	6616-06			5878-02
(NAME)	Blackmax	D Const	MATX						D Const	Southwind			Interstate
(LOC)	Bartonville	Rockdale	Sterling						Rockdale	Thornton			Chicago
(ADD. INFO)													PG52-34
									4.8	24.5	0.0	0.0	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 52-28
	17.0	29.0	10.0	0.0	0.0	0.0	0.0	0.0	40.0	4.0	0.0	0.0	100.0
	Mixture Blend:												Totals: ↕
	15.9	27.1	9.4	0.0	0.0	0.0	0.0	0.0	39.3	5.0	0.0	0.0	100.0

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	79.0	98.6	100.0	100.0	100.0	100.0	100.0	100.0	99.0	100.0	100.0	100.0	95	90-100
No.4 (4.75mm)	26.0	21.0	100.0	100.0	100.0	100.0	100.0	100.0	73.0	95.0	100.0	100.0	54	36-69
No.8 (2.36mm)	7.0	4.0	78.0	100.0	100.0	100.0	100.0	100.0	51.0	92.0	100.0	100.0	34	32-52
No.16 (1.18mm)	5.0	3.7	45.0	100.0	100.0	100.0	100.0	100.0	38.0	72.0	100.0	100.0	25	10-32
No.30 (600µm)	5.0	3.5	21.0	100.0	100.0	100.0	100.0	100.0	29.0	53.0	100.0	100.0	18	
No.50 (300µm)	4.0	3.2	16.0	100.0	100.0	100.0	100.0	100.0	20.0	43.0	100.0	100.0	13	4-15
No.100 (150µm)	3.0	2.5	10.0	100.0	100.0	100.0	100.0	95.0	14.0	35.0	100.0	100.0	9	3-10
No.200(75µm)	2.1	2.2	6.5	100.0	100.0	100.0	100.0	90.0	9.7	25.5	100.0	100.0	6.6	4-6
Bulk Sp Gr	3.511	2.473	3.353	1.000	1.000	1.000	1.000	1.000	2.660	2.500	1.000	1.000	2.763	Dust/AB
Absorption, %	1.60	4.70	4.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.58	Ratio
												SP GR AB	1.040	1.02

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int.	7								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.5	2.193	2.599	15.6	25.0	37.5	9.38	4.45	1.11
MIX 2	6.0	2.205	2.573	14.3	25.0	42.8	10.69	5.04	1.02
MIX 3	6.5	2.227	2.552	12.7	24.6	48.3	11.91	5.56	1.01
MIX 4	7.0	2.240	2.536	11.7	24.6	52.6	12.92	6.00	1.07

DATA for N-des.	70									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.5	2.439	2.599	6.2	16.6	62.9	10.44	4.45	2.847	1.11
MIX 2	6.0	2.453	2.573	4.7	16.6	71.8	11.89	5.04	2.840	1.02
MIX 3	6.5	2.484	2.552	2.7	15.9	83.3	13.28	5.56	2.839	1.01
MIX 4	7.0	2.487	2.536	1.9	16.3	88.2	14.35	6.00	2.844	1.07

Hamburg Wheel Information	
Sample No. Passes	20000
Sample Wheel Depth	-5.62

TSR Information	
Conditioned	122.2
Unconditioned	133.5
TSR	0.92
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes											
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa) Target	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
70	6.4	2.478	2.555	3.0	16.1	81.3	2.839	2.763	0.92	3.1	3.3	48.3

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED: 2 HOURS @ 295

Lab Preparing Design: PP

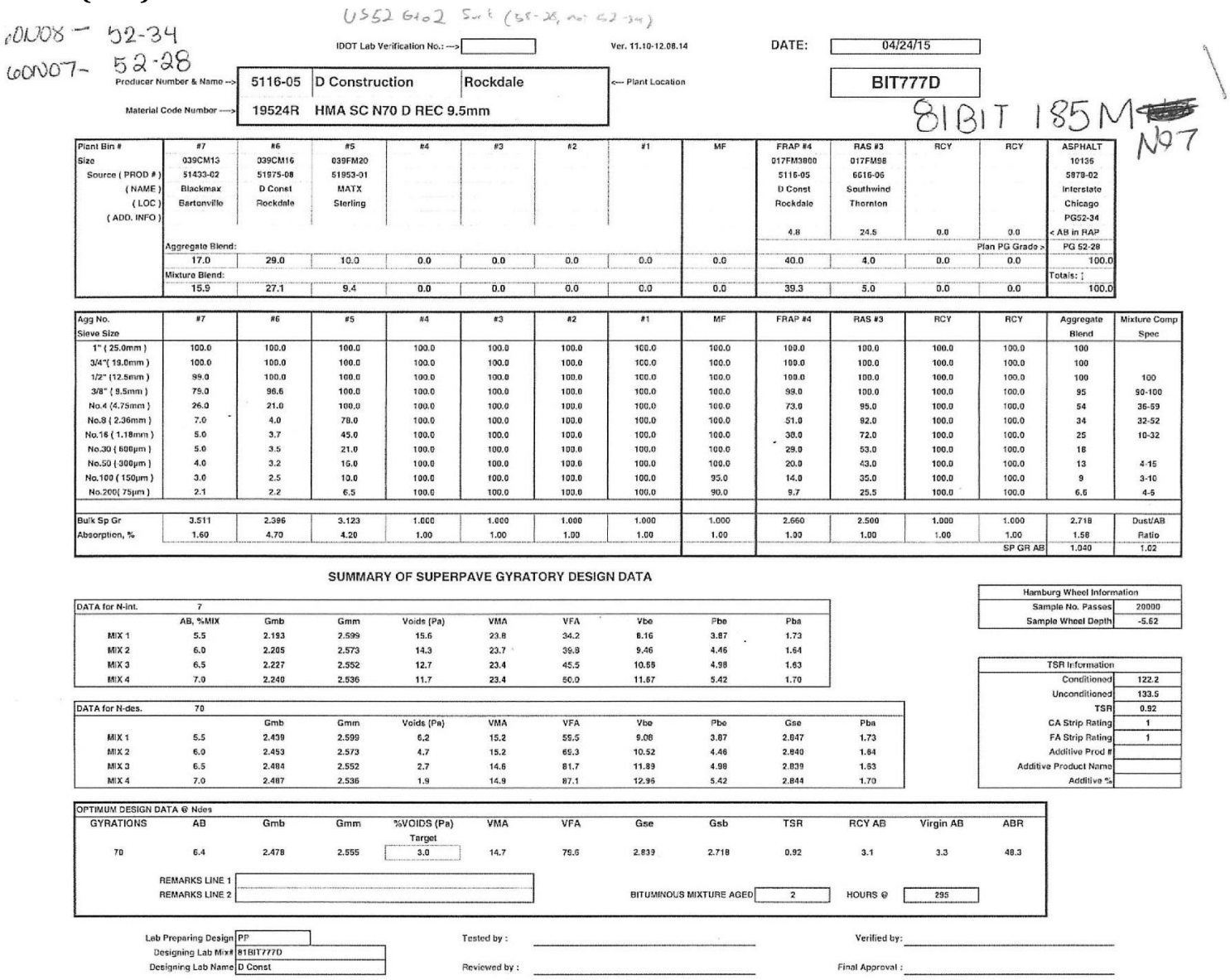
Designing Lab Mix#: 81BIT777D

Designing Lab Name: D Const

Tested by: _____ Verified by: _____

Reviewed by: _____ Final Approval: _____

A.6: Mix 185M (N07)



IDOT Lab Verification No.: ---> Ver. 11.10-12.08.14 DATE: 04/24/15

Producer Number & Name ---> 5116-05 | D Construction | Rockdale <--- Plant Location

Material Code Number ---> 19524R HMA SC N70 D REC 9.5mm

BIT777D

81BIT 185M N07

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	ASPHALT
Size	039CM13	039CM16	039FM20						017FM3800	017FM98			10136
Source (PROD #)	51433-02	51975-08	51953-01						5116-05	6616-06			5879-02
(NAME)	Blackmax	D Const	MATX						D Const	Southwind			Interstate
(LOC)	Bartonville	Rockdale	Sterling						Rockdale	Thornton			Chicago
(ADD. INFO)													PG52-34
									4.8	24.5	0.0	0.0	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 52-28
	17.0	29.0	10.0	0.0	0.0	0.0	0.0	0.0	40.0	4.0	0.0	0.0	100.0
	Mixture Blend:												Totals: ↕
	15.9	27.1	9.4	0.0	0.0	0.0	0.0	0.0	39.3	5.0	0.0	0.0	100.0

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	75.0	96.6	100.0	100.0	100.0	100.0	100.0	100.0	98.0	100.0	100.0	100.0	95	90-100
No.4 (4.75mm)	26.0	21.0	100.0	100.0	100.0	100.0	100.0	100.0	73.0	95.0	100.0	100.0	54	36-59
No.8 (2.36mm)	7.0	4.0	78.0	100.0	100.0	100.0	100.0	100.0	51.0	92.0	100.0	100.0	34	32-52
No.16 (1.18mm)	5.0	3.7	45.0	100.0	100.0	100.0	100.0	100.0	38.0	72.0	100.0	100.0	25	10-32
No.30 (600µm)	5.0	3.5	21.0	100.0	100.0	100.0	100.0	100.0	29.0	53.0	100.0	100.0	18	
No.50 (300µm)	4.0	3.2	16.0	100.0	100.0	100.0	100.0	100.0	20.0	43.0	100.0	100.0	13	4-15
No.100 (150µm)	3.0	2.5	10.0	100.0	100.0	100.0	100.0	95.0	14.0	35.0	100.0	100.0	9	3-10
No.200(75µm)	2.1	2.2	6.5	100.0	100.0	100.0	100.0	90.0	9.7	25.5	100.0	100.0	6.6	4-6
Bulk Sp Gr	3.511	2.396	3.123	1.000	1.000	1.000	1.000	1.000	2.660	2.500	1.000	1.000	2.718	Dust/AB
Absorption, %	1.60	4.70	4.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.58	Ratio
												SP GR AB	1.040	1.02

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int.	7								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.5	2.193	2.599	15.6	23.8	34.2	8.16	3.87	1.73
MIX 2	6.0	2.205	2.573	14.3	23.7	39.8	9.46	4.46	1.64
MIX 3	6.5	2.227	2.552	12.7	23.4	45.5	10.58	4.98	1.63
MIX 4	7.0	2.240	2.536	11.7	23.4	50.0	11.67	5.42	1.70

DATA for N-des.	70									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.5	2.439	2.599	6.2	15.2	59.5	9.08	3.87	2.847	1.73
MIX 2	6.0	2.453	2.573	4.7	15.2	69.3	10.52	4.46	2.840	1.64
MIX 3	6.5	2.484	2.552	2.7	14.6	81.7	11.89	4.98	2.839	1.63
MIX 4	7.0	2.487	2.536	1.9	14.9	87.1	12.96	5.42	2.844	1.70

Hamburg Wheel Information	
Sample No. Passes	20000
Sample Wheel Depth	-5.62

TSR Information	
Conditioned	122.2
Unconditioned	133.5
TSR	0.92
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes

GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa) Target	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
70	6.4	2.478	2.555	3.0	14.7	79.6	2.839	2.718	0.92	3.1	3.3	48.3

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED 2 HOURS @ 295

Lab Preparing Design PP

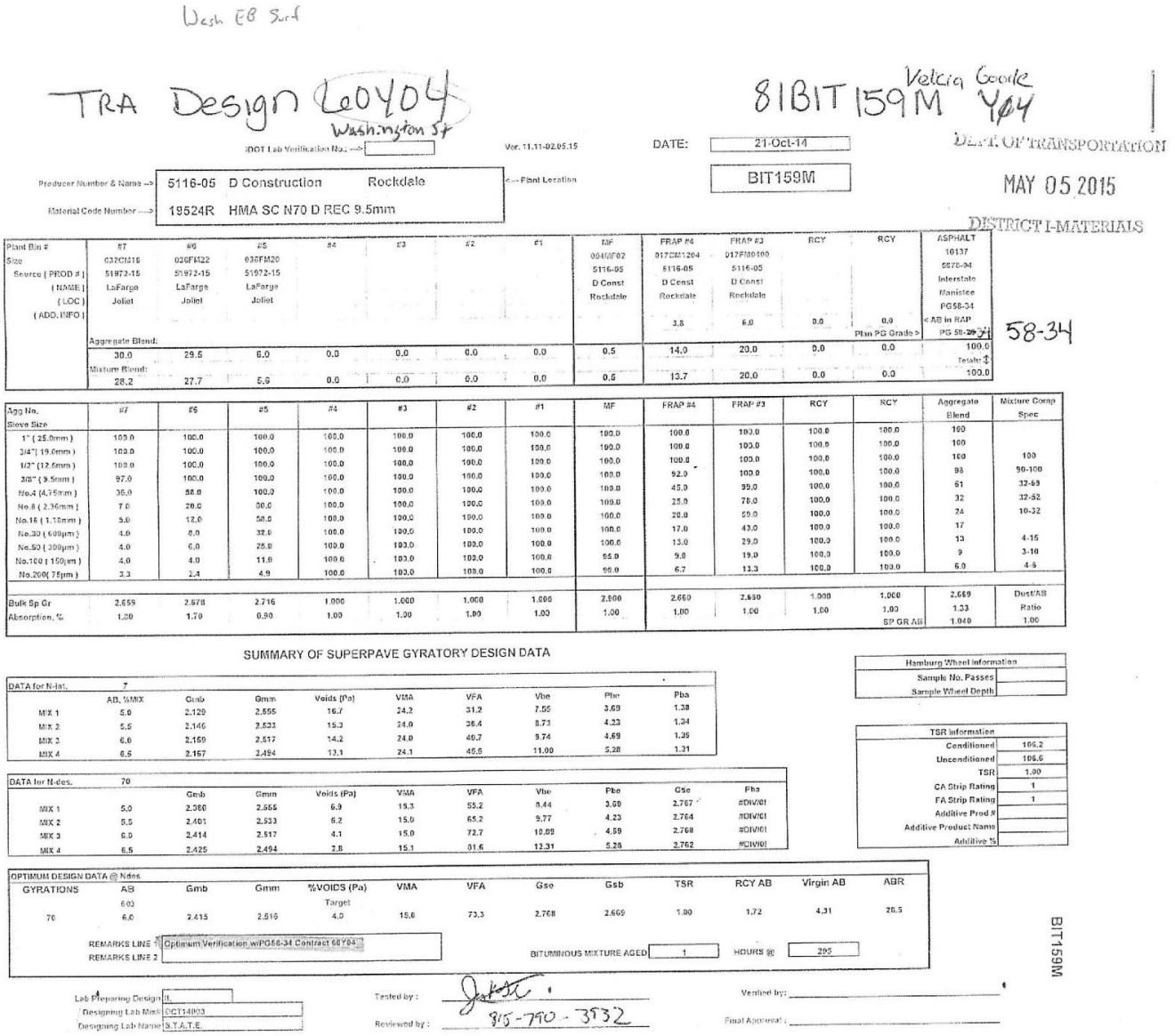
Designing Lab Mix# 81BIT777D

Designing Lab Name D Const

Tested by : _____ Verified by: _____

Reviewed by : _____ Final Approval : _____

A.7: Mix 159M (Y04)



Wash EB Surf

TRA Design 160404 Washington St

81BIT 159M Velcia Goode Y04

IDOT Lab Verification No.: ---> Ver. 11.11-02.05.15

DATE: 21-Oct-14

DEPT. OF TRANSPORTATION

MAY 05 2015

DISTRICT 1-MATERIALS

Producer Number & Name --> 5116-05 D Construction Rockdale <--- Plant Location

Material Code Number ---> 19524R HMA SC N70 D REC 9.5mm

BIT159M

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	FRAP #3	RCY	RCY	ASPHALT
Size	032CM16	020FM22	030FM20					004MF02	017CM1204	017FM0100			10137
Source (PROD #)	51972-15	51972-15	51972-15					5116-05	5116-05	5116-05			5070-34
(NAME)	LaFarge	LaFarge	LaFarge					D Const	D Const	D Const			Interstate
(LOC)	Joliet	Joliet	Joliet					Rockdale	Rockdale	Rockdale			Manistee
(ADD. INFO)													PG58-34
									3.8	6.0	0.0	0.0	< AB in RAP
												Plan PG Grade >	PG 58-28 → 58-34
	Aggregate Blend:												
	30.0	29.5	6.0	0.0	0.0	0.0	0.0	0.5	14.0	20.0	0.0	0.0	100.0
	Mixture Blend:												Totals:
	28.2	27.7	5.6	0.0	0.0	0.0	0.0	0.5	13.7	20.0	0.0	0.0	100.0

Agg No.	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	FRAP #3	RCY	RCY	Aggregate Blend	Mixture Comp Spec
Sieve Size														
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4" (19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	97.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	92.0	100.0	100.0	100.0	98	90-100
No.4 (4.75mm)	36.0	58.0	100.0	100.0	100.0	100.0	100.0	100.0	45.0	99.0	100.0	100.0	61	32-69
No.8 (2.36mm)	7.0	20.0	90.0	100.0	100.0	100.0	100.0	100.0	25.0	78.0	100.0	100.0	32	32-52
No.16 (1.18mm)	5.0	12.0	58.0	100.0	100.0	100.0	100.0	100.0	20.0	59.0	100.0	100.0	24	10-32
No.30 (600µm)	4.0	8.0	32.0	100.0	100.0	100.0	100.0	100.0	17.0	43.0	100.0	100.0	17	
No.50 (300µm)	4.0	6.0	25.0	100.0	100.0	100.0	100.0	100.0	13.0	29.0	100.0	100.0	13	4-15
No.100 (150µm)	4.0	4.0	11.0	100.0	100.0	100.0	100.0	99.0	9.0	19.0	100.0	100.0	9	3-10
No.200(75µm)	3.3	2.4	4.9	100.0	100.0	100.0	100.0	99.0	6.7	13.3	100.0	100.0	6.0	4-8
Bulk Sp Gr	2.659	2.678	2.716	1.000	1.000	1.000	1.000	2.800	2.660	2.630	1.000	1.000	2.669	Dust/AB
Absorption, %	1.00	1.70	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.33	Ratio
												SP GR AB	1.040	1.00

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-Int.	7								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.0	2.129	2.555	16.7	24.2	31.2	7.55	3.69	1.38
MIX 2	5.5	2.146	2.533	15.3	24.0	36.4	8.73	4.23	1.34
MIX 3	6.0	2.159	2.517	14.2	24.0	40.7	9.74	4.69	1.35
MIX 4	6.5	2.167	2.494	13.1	24.1	45.6	11.00	5.28	1.31

DATA for N-des.	70									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.0	2.360	2.555	6.9	15.3	55.2	8.44	3.69	2.767	#DIV/0!
MIX 2	5.5	2.401	2.533	6.2	15.0	65.2	9.77	4.23	2.764	#DIV/0!
MIX 3	6.0	2.414	2.517	4.1	15.0	72.7	10.89	4.69	2.768	#DIV/0!
MIX 4	6.5	2.425	2.494	2.8	15.1	81.6	12.31	5.28	2.762	#DIV/0!

OPTIMUM DESIGN DATA @ Ndes												
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	6.03			Target								
70	6.0	2.415	2.516	4.0	15.0	73.3	2.768	2.669	1.00	1.72	4.31	28.5

REMARKS LINE 1: Optimum Verification w/PG58-34 Contract 60Y04

REMARKS LINE 2:

BITUMINOUS MIXTURE AGED: 1 HOURS @: 295

Hamburg Wheel Information	
Sample No. Passes	
Sample Wheel Depth	

TSR Information	
Conditioned	106.2
Unconditioned	105.6
TSR	1.00
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

Lab Preparing Design: IL

Designing Lab Mix #: 06T14003

Designing Lab Name: S.T.A.T.E.

Tested by:

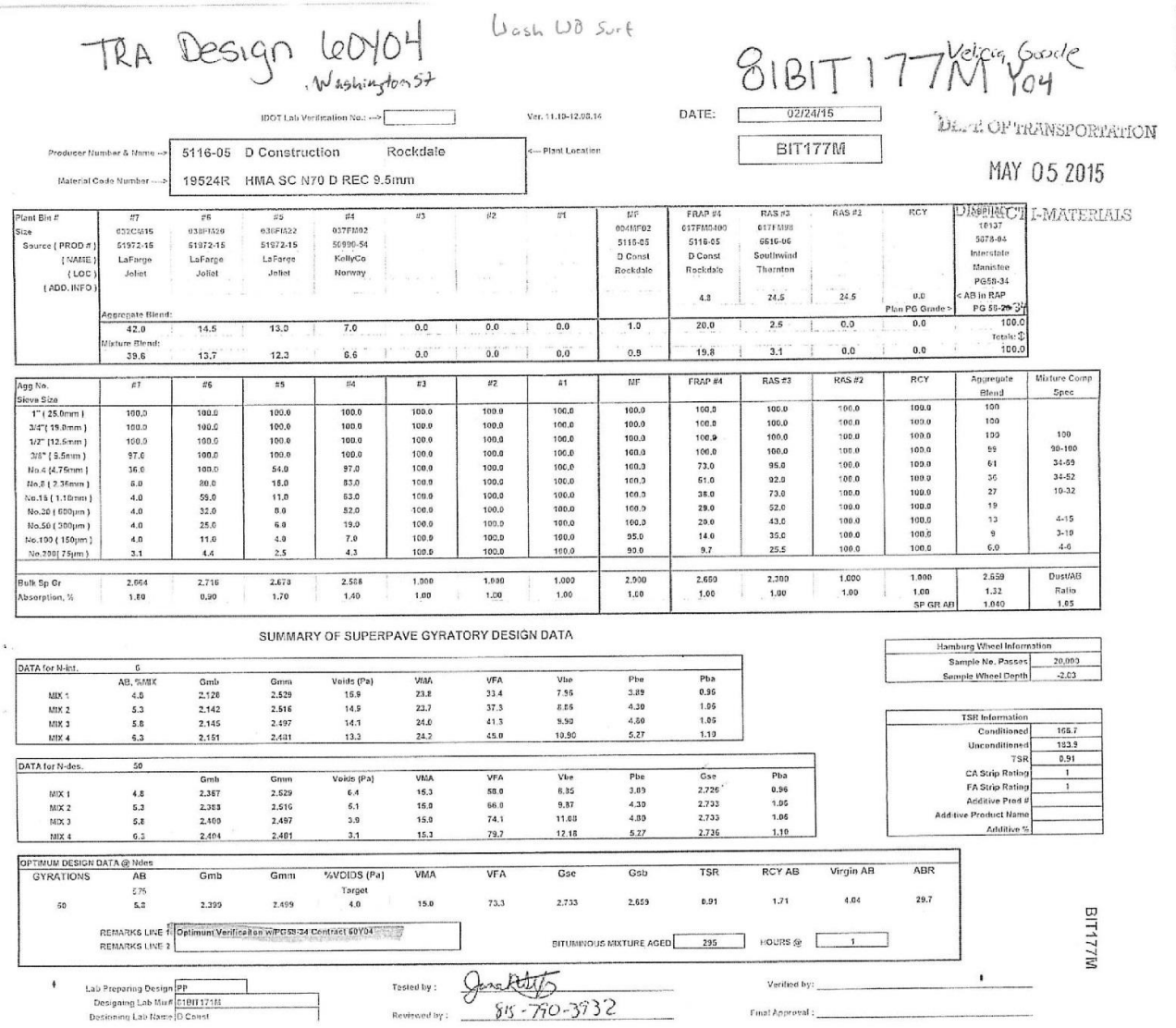
Reviewed by: 815-790-3532

Verified by:

Final Approval:

BIT159M

A.8: Mix 177M



TRA Design 60Y04
Washington St
Wash UB Surf

8IBIT 177M Vetica Goode Y04

IDOT Lab Verification No.: -->
Ver. 11.10-12.08.14

DATE: 02/24/15

DEPT. OF TRANSPORTATION
MAY 05 2015
DISTRICT 1-MATERIALS

Producer Number & Name --> 5116-05 D Construction Rockdale <-- Plant Location
Material Code Number --> 19524R HMA SC N70 D REC 9.5mm

BIT177M

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RAS #2	RCY	DISTRICT 1-MATERIALS
Size	032CM16	038FM20	038FM22	037FM02				004MF02	017FM04M0	017FM08			10137
Source (PROD #)	51972-15	51972-15	51972-15	50990-54				5116-05	5116-05	6616-06			5078-04
(NAME)	LaFarge	LaFarge	LaFarge	KellyCo				D Const	D Const	Southwind			Interstate
(LOC)	Joliet	Joliet	Joliet	Norway				Rockdale	Rockdale	Thornton			Manistee
(ADD. INFO)													PG58-34
									4.8	24.5	24.5	0.0	< AB in RAP
												Plan PG Grade>	PG 58-28 34
Aggregate Blend:	42.0	14.5	13.0	7.0	0.0	0.0	0.0	1.0	20.0	2.5	0.0	0.0	100.0
Mixture Blend:	39.6	13.7	12.3	6.6	0.0	0.0	0.0	0.9	19.8	3.1	0.0	0.0	Totals: 100.0

Agg No. / Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RAS #2	RCY	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4" (19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	97.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99	90-100
No.4 (4.75mm)	36.0	100.0	54.0	97.0	100.0	100.0	100.0	100.0	73.0	95.0	100.0	100.0	61	34-59
No.8 (2.36mm)	6.0	80.0	18.0	83.0	100.0	100.0	100.0	100.0	51.0	92.0	100.0	100.0	36	34-52
No.16 (1.18mm)	4.0	59.0	11.0	63.0	100.0	100.0	100.0	100.0	38.0	73.0	100.0	100.0	27	10-32
No.30 (600µm)	4.0	32.0	8.0	52.0	100.0	100.0	100.0	100.0	29.0	52.0	100.0	100.0	19	
No.50 (300µm)	4.0	25.0	6.0	19.0	100.0	100.0	100.0	100.0	20.0	43.0	100.0	100.0	13	4-15
No.100 (150µm)	4.0	11.0	4.0	7.0	100.0	100.0	100.0	95.0	14.0	35.0	100.0	100.0	9	3-10
No.200 (75µm)	3.1	4.4	2.5	4.3	100.0	100.0	100.0	90.0	9.7	25.5	100.0	100.0	6.0	4-6
Bulk Sp Gr	2.664	2.716	2.673	2.568	1.000	1.000	1.000	2.900	2.650	2.300	1.000	1.000	2.659	Dust/AB
Absorption, %	1.80	0.90	1.70	1.40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.32	Ratio
												SP GR AB	1.040	1.05

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-Int.	6								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	4.8	2.128	2.529	15.9	23.8	33.4	7.95	3.89	0.96
MIX 2	5.3	2.142	2.516	14.9	23.7	37.3	8.85	4.30	1.05
MIX 3	5.8	2.145	2.497	14.1	24.0	41.3	9.90	4.80	1.05
MIX 4	6.3	2.151	2.481	13.3	24.2	45.0	10.90	5.27	1.10

DATA for N-des.	50									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	4.8	2.367	2.529	6.4	15.3	58.0	8.85	3.89	2.726	0.96
MIX 2	5.3	2.383	2.516	5.1	15.8	68.0	9.87	4.30	2.733	1.05
MIX 3	5.8	2.400	2.497	3.9	15.9	74.1	11.03	4.80	2.733	1.05
MIX 4	6.3	2.404	2.481	3.1	15.3	79.7	12.18	5.27	2.736	1.10

Hamburg Wheel Information	
Sample No. Passes	20,000
Sample Wheel Depth	-2.03

TSR Information	
Conditioned	165.7
Unconditioned	183.9
TSR	0.91
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes												
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	575			Target								
50	5.3	2.399	2.499	4.0	15.0	73.3	2.733	2.659	0.91	1.71	4.04	29.7

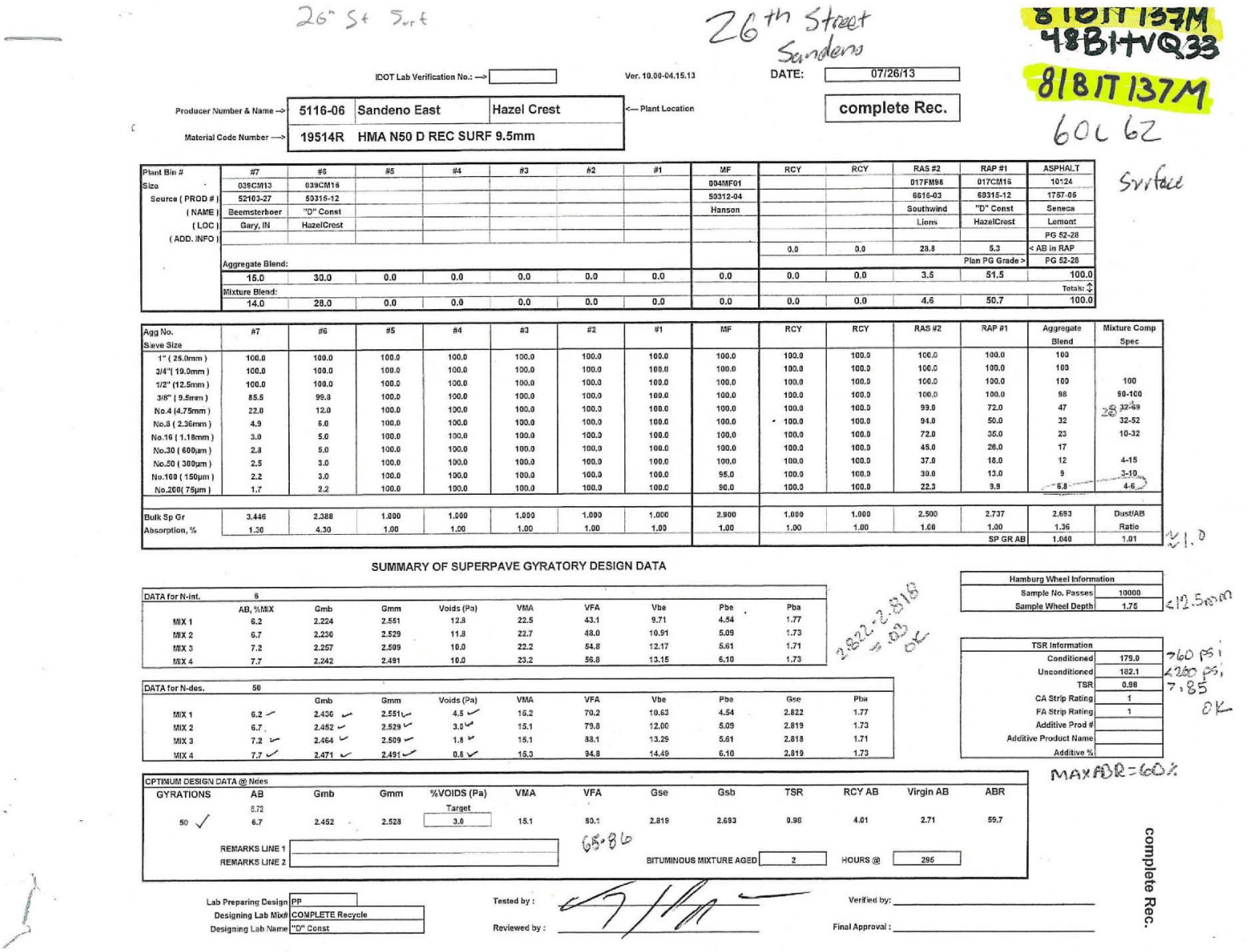
REMARKS LINE 1: Optimum Verification w/PG58-34 Contract 60Y04
REMARKS LINE 2:
BITUMINOUS MIXTURE AGED: 295 HOURS @: 1

Lab Preparing Design: PP
Designing Lab Mix#: 01BIT121M
Designing Lab Name: D Const

Tested by: Jana Potts
Reviewed by: 815-790-3732
Verified by:
Final Approval:

BIT177M

A.9: Mix 137M



26th Street Sandeno

8 IBIT 137M
48BITVQ33
8IBIT 137M
60 62

IDOT Lab Verification No.: —> Ver. 10.00-04.15.13 DATE: 07/26/13

Producer Number & Name —> 5116-06 | Sandeno East | Hazel Crest <— Plant Location

Material Code Number —> 19514R | HMA N50 D REC SURF 9.5mm

complete Rec.

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	RAS #2	RAP #1	ASPHALT
Size	039CM13	039CM16						004MF01			017FM98	017CM16	10124
Source (PROD #)	52103-27	59316-12						59312-04			6816-03	59315-12	1757-06
(NAME)	Beemsterboer	"D" Const						Hanson			Southwind	"D" Const	Seneca
(LOC)	Gary, IN	HazelCrest									Lions	HazelCrest	Lemont
(ADD. INFO)													PG 52-28
									0.0	0.0	28.8	5.3	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 52-28
	15.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	51.5	100.0
	Mixture Blend:												Totals:
	14.0	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	50.7	100.0

Surface

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	RAS #2	RAP #1	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	85.5	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98	90-100
No.4 (4.75mm)	22.0	12.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	72.0	47	28 32-52
No.8 (2.36mm)	4.9	6.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.0	50.0	32	32-52
No.16 (1.18mm)	3.0	5.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	72.0	35.0	23	10-32
No.30 (600µm)	2.8	5.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	45.0	26.0	17	
No.50 (300µm)	2.5	3.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	37.0	18.0	12	4-15
No.100 (150µm)	2.2	3.0	100.0	100.0	100.0	100.0	100.0	95.0	100.0	100.0	30.0	13.0	9	3-10
No.200(75µm)	1.7	2.2	100.0	100.0	100.0	100.0	100.0	90.0	100.0	100.0	22.3	9.9	6.8	4-6
Bulk Sp Gr	3.446	2.388	1.000	1.000	1.000	1.000	1.000	2.900	1.000	1.000	2.500	2.737	2.693	Dust/AB
Absorption, %	1.30	4.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.36	Ratio
												SP GR AB	1.040	1.01

~1.0

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int.	6								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	6.2	2.224	2.551	12.8	22.5	43.1	9.71	4.54	1.77
MIX 2	6.7	2.230	2.529	11.8	22.7	48.0	10.91	5.09	1.73
MIX 3	7.2	2.257	2.509	10.0	22.2	54.8	12.17	5.61	1.71
MIX 4	7.7	2.242	2.491	10.0	23.2	56.8	13.15	6.10	1.73

2.82-2.818 = .002 OK

DATA for N-des.	50									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	6.2	2.436	2.551	4.5	16.2	70.2	10.63	4.54	2.822	1.77
MIX 2	6.7	2.452	2.529	3.0	15.1	79.8	12.00	5.09	2.819	1.73
MIX 3	7.2	2.464	2.509	1.8	15.1	88.1	13.29	5.61	2.818	1.71
MIX 4	7.7	2.471	2.491	0.8	15.3	94.8	14.49	6.10	2.819	1.73

Hamburg Wheel Information	
Sample No. Passes	10000
Sample Wheel Depth	1.75

<12.5mm

TSR Information	
Conditioned	179.0
Unconditioned	182.1
TSR	0.98
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

>60 PSI
>80 PSI
7,85
OK

MAX ABR = 60%

OPTIMUM DESIGN DATA @ Ndes											
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	6.72			Target								
50 ✓	6.7	2.452	2.528	3.0	15.1	80.1	2.819	2.693	0.98	4.01	2.71	59.7

REMARKS LINE 1
REMARKS LINE 2

65-80

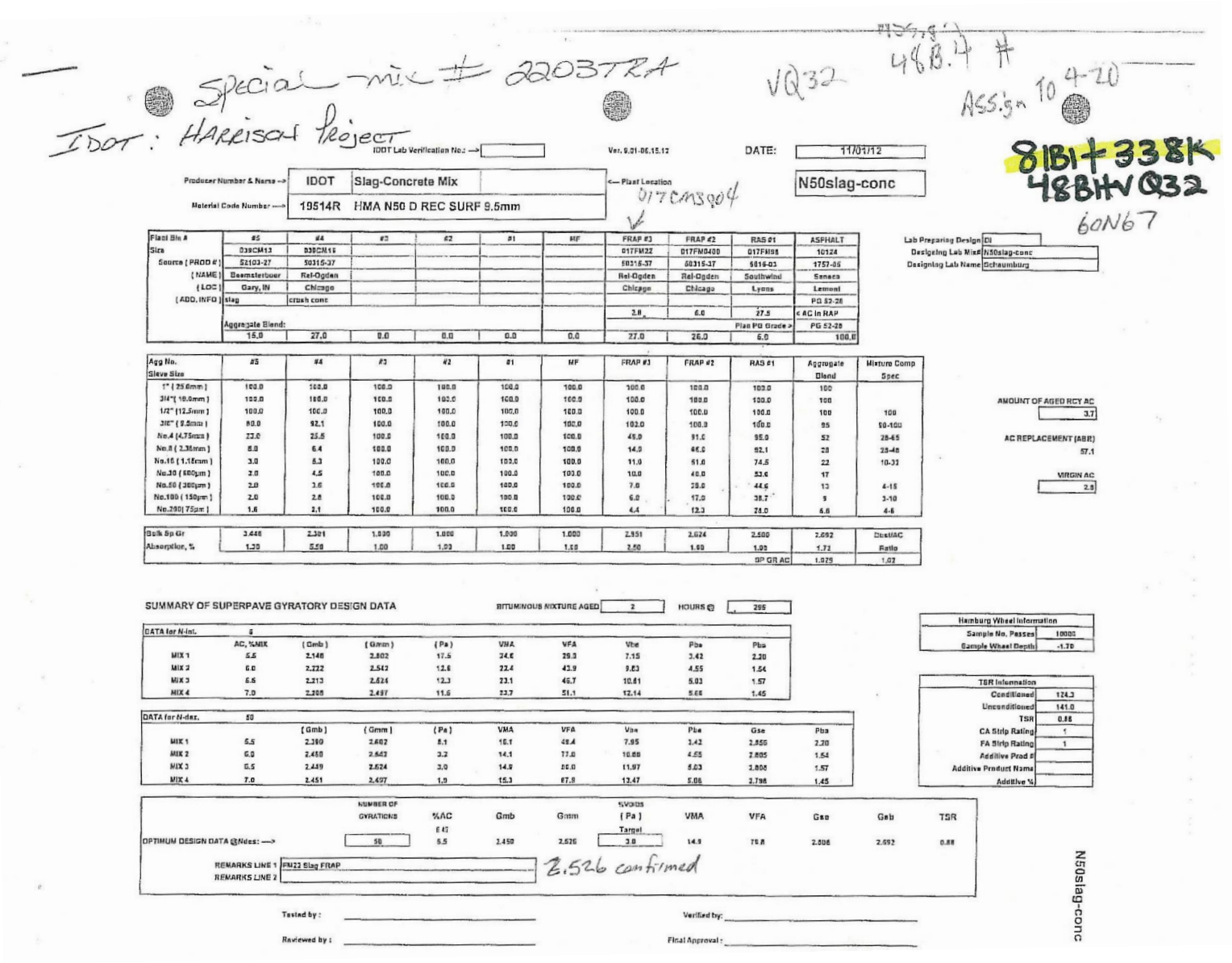
BITUMINOUS MIXTURE AGED: 2 HOURS @ 295

complete Rec.

Lab Preparing Design: PP
Designing Lab Mix#: COMPLETE Recycle
Designing Lab Name: "D" Const

Tested by:
Reviewed by:
Verified by:
Final Approval:

A.10: Mix 338K



Special mix # 2203TRA

IDOT: HARRISON Project

VQ32

488.4 #

Ass'n 10 4-20

IDOT Lab Verification No.: —→

Ver. 9.01-06.15.12

DATE: 11/01/12

Producer Number & Name —→ IDOT | Slag-Concrete Mix | ← Plant Location | N50slag-conc

Material Code Number —→ 19514R HMA N50 D REC SURF 9.5mm

017CM3904

8181+338K
488HVQ32
60N67

Plant Bin #	#5	#4	#3	#2	#1	MF	FRAP #3	FRAP #2	RAS #1	ASPHALT
Size	039CM13	039CM15					017FM22	017FM9400	017FM98	10124
Source (PROD #)	52103-27	50315-37					50315-37	50315-37	5016-03	1757-05
(NAME)	Beamsterbuer	Rel-Ogden					Rel-Ogden	Rel-Ogden	Southwind	Seneca
(LOC)	Gary, IN	Chicago					Chicago	Chicago	Lyons	Lemont
(ADD. INFO)	slag	crush conc								PG 52-28
							3.8	6.0	27.5	< AC in RAP
	Aggregate Blend:								Plan PG Grade >	PG 52-28
	15.0	27.0	0.0	0.0	0.0	0.0	27.0	26.0	6.0	100.0

Lab Preparing Design: DI
Designing Lab Mix#: N50slag-conc
Designing Lab Name: Schaumburg

Agg No. / Sieve Size	#5	#4	#3	#2	#1	MF	FRAP #3	FRAP #2	RAS #1	Aggregate Blend	Mixture Comp Spec	
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100		
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100		
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100	
3/8" (9.5mm)	80.0	92.1	100.0	100.0	100.0	100.0	102.0	100.3	100.0	95	90-100	
No.4 (4.75mm)	23.0	25.5	100.0	100.0	100.0	100.0	46.0	91.0	95.0	52	28-45	
No.8 (2.36mm)	6.0	6.4	100.0	100.0	100.0	100.0	14.0	46.0	92.1	28	28-45	
No.16 (1.18mm)	3.0	5.3	100.0	100.0	100.0	100.0	11.0	61.0	74.5	22	10-31	
No.30 (600µm)	2.0	4.5	100.0	100.0	100.0	100.0	10.0	40.0	53.6	17		
No.50 (300µm)	2.0	3.6	100.0	100.0	100.0	100.0	7.0	25.0	44.6	13	4-15	
No.100 (150µm)	2.0	2.8	100.0	100.0	100.0	100.0	6.0	17.0	38.7	9	3-10	
No.200(75µm)	1.6	2.1	100.0	100.0	100.0	100.0	4.4	12.3	28.0	6.6	4-6	
Bulk Sp Gr	2.448	2.391	1.000	1.000	1.000	1.000	2.551	2.624	2.500	2.692	Dust/AC	
Absorption, %	1.39	5.58	1.00	1.00	1.00	1.00	2.50	1.00	1.00	1.72	Ratio	
									SP GR AC	1.025	1.07	

AMOUNT OF AGED RCY AC: 3.7

AC REPLACEMENT (ABR): 57.1

VIRGIN AC: 2.8

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

BITUMINOUS MIXTURE AGED: 2 HOURS @: 295

DATA for N-ini. 6

	AC, %MIX	(Gmb)	(Gmm)	(Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.5	2.148	2.802	17.5	24.6	29.0	7.15	3.42	2.20
MIX 2	6.0	2.222	2.542	12.6	22.4	43.9	9.83	4.55	1.54
MIX 3	6.5	2.313	2.624	12.3	23.1	46.7	10.81	5.03	1.57
MIX 4	7.0	2.395	2.497	11.6	23.7	51.1	12.14	5.66	1.45

DATA for N-des. 50

		(Gmb)	(Gmm)	(Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.5	2.390	2.602	8.1	16.1	49.4	7.95	3.42	2.555	2.20
MIX 2	6.0	2.458	2.643	3.2	14.1	77.0	10.86	4.55	2.605	1.54
MIX 3	6.5	2.449	2.624	3.0	14.9	80.0	11.97	5.03	2.606	1.57
MIX 4	7.0	2.451	2.497	1.9	15.3	87.5	13.47	5.66	2.796	1.45

Hamburg Wheel Information

Sample No. Passes	10000
Sample Wheel Depth	-1.70

TSR Information

Conditioned	124.3
Unconditioned	141.0
TSR	0.88
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

	NUMBER OF GYRATIONS	%AC	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR
		Est.			Target					
OPTIMUM DESIGN DATA @Ndes: —→	50	6.5	2.450	2.526	3.0	14.9	79.8	2.606	2.692	0.88

REMARKS LINE 1: FM22 Slag FRAP
REMARKS LINE 2:

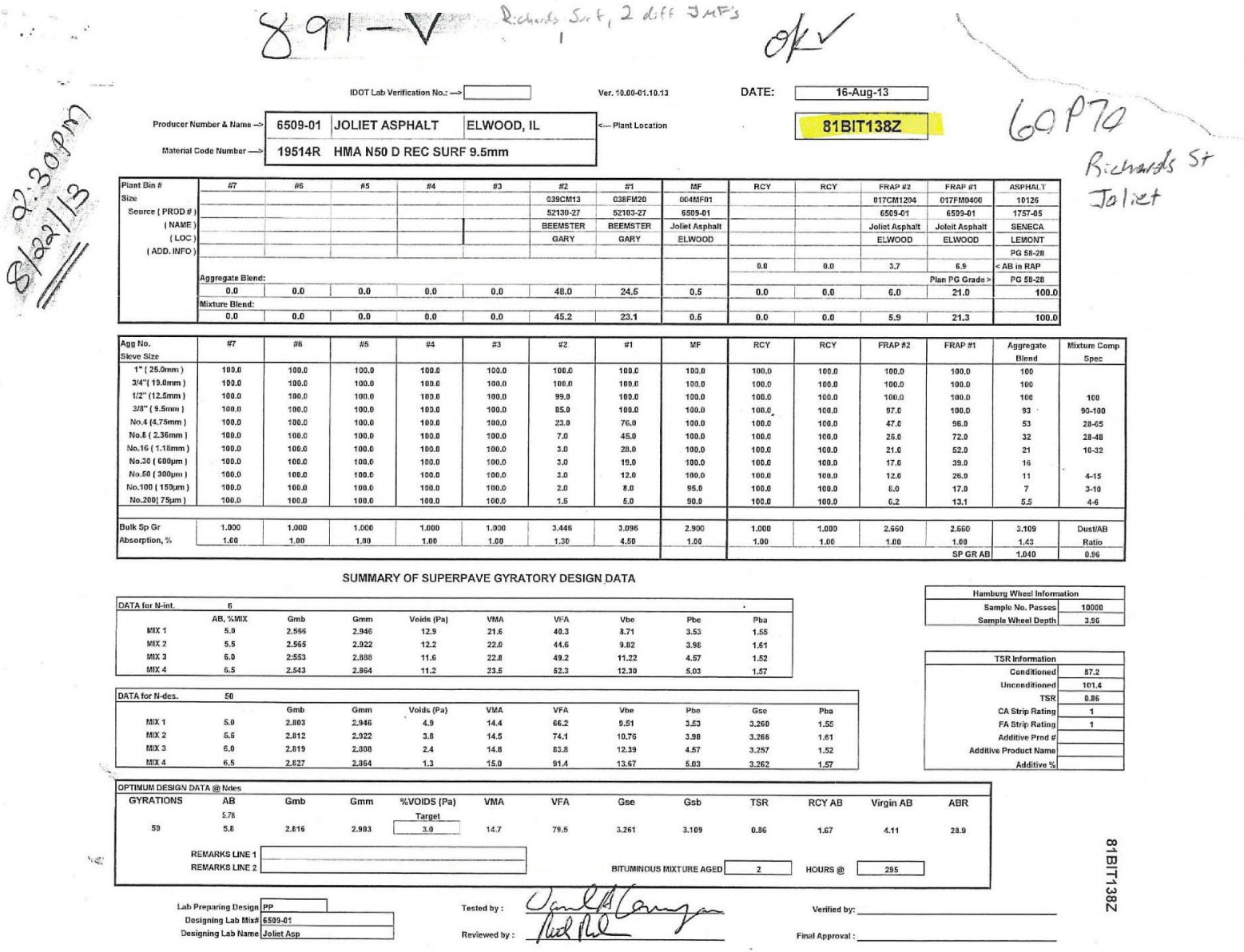
2.526 confirmed

Tested by: Verified by:

Reviewed by: Final Approval:

N50slag-conc

A.11: Mix 138Z



891-V Richards Surf, 2 diff JMF's ok✓

IDOT Lab Verification No.: —> Ver. 10.00-01.10.13 DATE: 16-Aug-13

Producer Number & Name —> 6509-01 | JOLIET ASPHALT | ELWOOD, IL <— Plant Location

Material Code Number —> 19514R HMA N50 D REC SURF 9.5mm

81BIT138Z

60 PG

Richards St Joliet

2:30pm 8/22/13

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	FRAP #2	FRAP #1	ASPHALT
Size						039CM13	038FM20	004MF01			017CM1204	017FM0400	10126
Source (PROD #)						52130-27	52103-27	6509-01			6509-01	6509-01	1757-05
(NAME)						BEEMSTER	BEEMSTER	Joliet Asphalt			Joliet Asphalt	Joleit Asphalt	SENECA
(LOC)						GARY	GARY	ELWOOD			ELWOOD	ELWOOD	LEMONT
(ADD. INFO)													PG 58-28
									0.0	0.0	3.7	5.9	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 58-28
	0.0	0.0	0.0	0.0	0.0	48.0	24.5	0.5	0.0	0.0	6.0	21.0	100.0
	Mixture Blend:												
	0.0	0.0	0.0	0.0	0.0	45.2	23.1	0.5	0.0	0.0	5.9	21.3	100.0

Agg No. Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	RCY	RCY	FRAP #2	FRAP #1	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	100.0	100.0	100.0	100.0	100.0	85.0	100.0	100.0	100.0	100.0	97.0	100.0	93	90-100
No.4 (4.75mm)	100.0	100.0	100.0	100.0	100.0	23.0	76.0	100.0	100.0	100.0	47.0	96.0	53	28-65
No.8 (2.36mm)	100.0	100.0	100.0	100.0	100.0	7.0	45.0	100.0	100.0	100.0	26.0	72.0	32	28-48
No.16 (1.18mm)	100.0	100.0	100.0	100.0	100.0	3.0	28.0	100.0	100.0	100.0	21.0	52.0	21	10-32
No.30 (600µm)	100.0	100.0	100.0	100.0	100.0	3.0	19.0	100.0	100.0	100.0	17.0	39.0	16	
No.50 (300µm)	100.0	100.0	100.0	100.0	100.0	3.0	12.0	100.0	100.0	100.0	12.0	26.0	11	4-15
No.100 (150µm)	100.0	100.0	100.0	100.0	100.0	2.0	8.0	95.0	100.0	100.0	8.0	17.0	7	3-10
No.200(75µm)	100.0	100.0	100.0	100.0	100.0	1.5	5.0	90.0	100.0	100.0	6.2	13.1	5.5	4-6
Bulk Sp Gr	1.000	1.000	1.000	1.000	1.000	3.446	3.096	2.900	1.000	1.000	2.660	2.660	3.109	Dust/AB
Absorption, %	1.00	1.00	1.00	1.00	1.00	1.30	4.50	1.00	1.00	1.00	1.00	1.00	1.43	Ratio
												SP GR AB	1.040	0.96

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-int.	6								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.0	2.566	2.946	12.9	21.6	40.3	8.71	3.53	1.55
MIX 2	5.5	2.565	2.922	12.2	22.0	44.6	9.82	3.98	1.61
MIX 3	6.0	2.553	2.888	11.6	22.8	49.2	11.22	4.57	1.52
MIX 4	6.5	2.543	2.864	11.2	23.5	52.3	12.30	5.03	1.57

DATA for N-des.	50								
	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.0	2.803	2.946	4.9	14.4	66.2	9.51	3.53	3.260	1.55
MIX 2	5.5	2.812	2.922	3.8	14.5	74.1	10.76	3.98	3.266	1.61
MIX 3	6.0	2.819	2.888	2.4	14.8	83.8	12.39	4.57	3.257	1.52
MIX 4	6.5	2.827	2.864	1.3	15.0	91.4	13.67	5.03	3.262	1.57

OPTIMUM DESIGN DATA @ Ndes												
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
	5.78			Target								
50	5.8	2.816	2.903	3.0	14.7	79.5	3.261	3.109	0.86	1.67	4.11	28.9

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED 2 HOURS @ 295

Hamburg Wheel Information	
Sample No. Passes	10000
Sample Wheel Depth	3.56

TSR Information	
Conditioned	87.2
Unconditioned	101.4
TSR	0.86
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

Lab Preparing Design PP

Designing Lab Mix# 6509-01

Designing Lab Name Joliet Asp

Tested by :

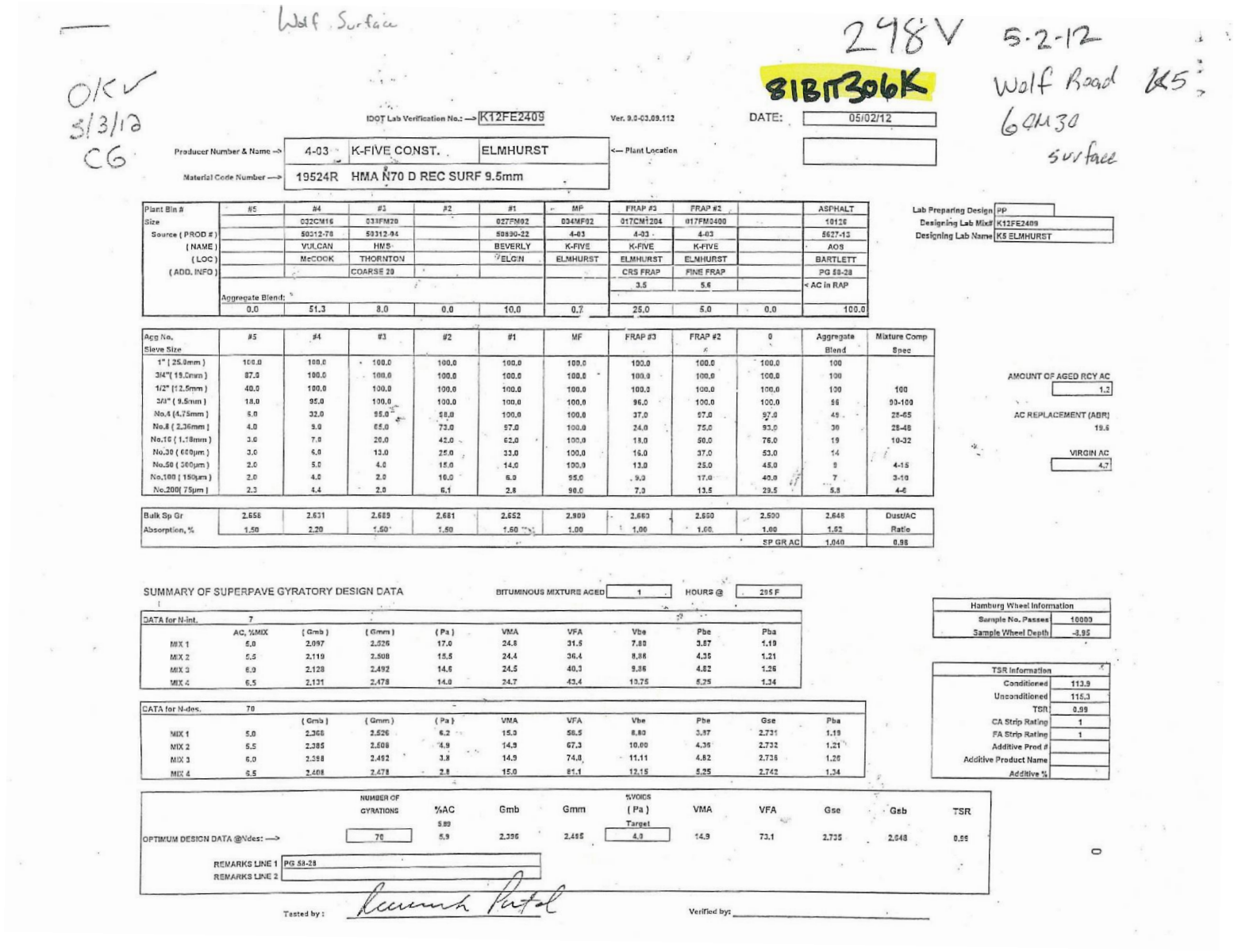
Reviewed by :

Verified by:

Final Approval :

81BIT138Z

A.12: Mix 306K



Wolf Surface

298V 5-2-12

81BIT306K

Wolf Road K5

6AM30

surface

OKV
5/3/12
CG

IDOT Lab Verification No.: → K12FE2409 Ver. 9.0-03.09.112 DATE: 05/02/12

Producer Number & Name → 4-03 K-FIVE CONST. ELMHURST ← Plant Location

Material Code Number → 19524R HMA N70 D REC SURF 9.5mm

Plant Bin #	#5	#4	#3	#2	#1	MF	FRAP #3	FRAP #2		ASPHALT
Size		032CM16	038FM20		027FM02	034MF02	017CM1204	017FM2400		10128
Source (PROD #)		50312-78	50312-94		50930-22	4-03	4-03	4-03		5627-13
(NAME)		VULCAN	HMS		BEVERLY	K-FIVE	K-FIVE	K-FIVE		AOS
(LOC)		McCOOK	THORNTON		ELGIN	ELMHURST	ELMHURST	ELMHURST		BARTLETT
(ADD. INFO)			COARSE 29				CRS FRAP	FINE FRAP		PG 58-28
	Aggregate Blend:						3.5	5.6		< AC in RAP
	0.0	51.3	8.0	0.0	10.0	0.7	25.0	5.0	0.0	100.0

Lab Preparing Design: PP
Designing Lab Mix#: K12FE2409
Designing Lab Name: K5 ELMHURST

Agg No. / Sieve Size	#5	#4	#3	#2	#1	MF	FRAP #3	FRAP #2	0	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	87.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	40.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	18.0	95.0	100.0	100.0	100.0	100.0	96.0	100.0	100.0	98	90-100
No.4 (4.75mm)	5.0	32.0	95.0	98.0	100.0	100.0	37.0	97.0	97.0	49	28-65
No.8 (2.36mm)	4.0	9.0	65.0	73.0	97.0	100.0	24.0	75.0	93.0	30	28-48
No.16 (1.18mm)	3.0	7.0	20.0	42.0	62.0	100.0	18.0	50.0	76.0	19	10-32
No.30 (600µm)	3.0	6.0	13.0	25.0	33.0	100.0	16.0	37.0	53.0	14	
No.50 (300µm)	2.0	5.0	4.0	15.0	14.0	100.0	13.0	25.0	45.0	9	4-15
No.100 (150µm)	2.0	4.0	2.0	10.0	6.0	95.0	9.0	17.0	40.0	7	3-10
No.200(75µm)	2.3	4.4	2.0	6.1	2.8	90.0	7.0	13.5	29.5	5.8	4-6

Bulk Sp Gr	2.658	2.631	2.689	2.681	2.652	2.909	2.663	2.650	2.500	2.648	Dust/AC
Absorption, %	1.50	2.20	1.50	1.50	1.50	1.00	1.00	1.00	1.00	1.52	Ratio
									SP GR AC	1.040	0.98

AMOUNT OF AGED RCY AC: 1.2

AC REPLACEMENT (ABR): 19.6

VIRGIN AC: 4.7

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

BITUMINOUS MIXTURE AGED: 1 HOURS @: 295 F

DATA for N-int. 7

	AC, %MIX	(Gmb)	(Gmm)	(Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	5.0	2.097	2.526	17.0	24.8	31.5	7.88	3.87	1.19
MIX 2	5.5	2.119	2.508	15.5	24.4	36.4	8.86	4.35	1.21
MIX 3	6.0	2.128	2.492	14.6	24.5	40.3	9.86	4.82	1.26
MIX 4	6.5	2.131	2.478	14.0	24.7	43.4	10.75	5.25	1.34

DATA for N-des. 70

		(Gmb)	(Gmm)	(Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	5.0	2.366	2.526	6.2	15.0	58.5	8.80	3.87	2.731	1.19
MIX 2	5.5	2.385	2.508	4.9	14.9	67.3	10.00	4.35	2.732	1.21
MIX 3	6.0	2.398	2.492	3.8	14.9	74.8	11.11	4.82	2.736	1.26
MIX 4	6.5	2.408	2.478	2.8	15.0	81.1	12.15	5.25	2.742	1.34

Hamburg Wheel Information

Sample No. Passes	10000
Sample Wheel Depth	-3.95

TSR Information

Conditioned	113.9
Unconditioned	115.3
TSR	0.99
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

	NUMBER OF GYRATIONS	%AC	Gmb	Gmm	%VOIDS (Pa)	VMA	VFA	Gse	Gsb	TSR
		5.89			Target					
OPTIMUM DESIGN DATA @Ndes: →	70	5.9	2.396	2.495	4.0	14.9	73.1	2.735	2.648	0.99

REMARKS LINE 1: PG 58-28

REMARKS LINE 2:

Tested by: Laurinda Pintal

Verified by:

A.13: Mix 163M (N07)

IDOT Lab Verification No.: ---> | Ver. 11.10-12.08.14 | DATE: 01/07/15

Producer Number & Name ---> 5116-05 | D Construction | Rockdale <--- Plant Location

Material Code Number ---> 19510R | HMA N50 4.75 REC | BIT163M | d : 4750

Plant Bin #	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	ASPHALT
Size	038FM22	038FM20		027FM12				004MF01	017FM3800	017FM98			10130
Source (PROD #)	51972-15	51972-15		50630-09				5116-05	5116-05	5616-06			1757-05
(NAME)	LaFarge	LaFarge		MSG				D Const	D Const	Southwind			Seneca
(LOC)	Joliet	Joliet		Morris				Rockdale	Rockdale	Thornton			Lament
(ADD. INFO)													SBS PG 70-28
									4.8	24.6	0.0	0.0	< AB in RAP
	Aggregate Blend:											Plan PG Grade >	PG 70-28
	7.0	44.0	0.0	18.0	0.0	0.0	0.0	2.0	25.0	4.0	0.0	0.0	100.0
	Mixture Blend:												Totals: ‡
	6.4	40.6	0.0	16.6	0.0	0.0	0.0	1.8	24.2	4.9	0.0	0.0	100.0

Agg No. / Sieve Size	#7	#6	#5	#4	#3	#2	#1	MF	FRAP #4	RAS #3	RCY	RCY	Aggregate Blend	Mixture Comp Spec
1" (25.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
3/4"(19.0mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
1/2" (12.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
3/8" (9.5mm)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
No.4 (4.75mm)	57.0	100.0	100.0	97.0	100.0	100.0	100.0	100.0	73.0	95.0	100.0	100.0	90	90-100
No.8 (2.36mm)	18.0	80.0	100.0	83.0	100.0	100.0	100.0	100.0	51.0	92.0	100.0	100.0	70	70-90
No.16 (1.18mm)	11.0	59.0	100.0	76.0	100.0	100.0	100.0	100.0	38.0	73.0	100.0	100.0	55	50-65
No.30 (600µm)	8.0	32.0	100.0	63.0	100.0	100.0	100.0	100.0	29.0	52.0	100.0	100.0	37	
No.50 (300µm)	6.0	25.0	100.0	15.0	100.0	100.0	100.0	100.0	20.0	43.0	100.0	100.0	23	15-30
No.100 (150µm)	4.0	11.0	100.0	2.0	100.0	100.0	100.0	95.0	14.0	35.0	100.0	100.0	12	10-18
No.200(75µm)	2.5	4.4	100.0	0.5	100.0	100.0	100.0	90.0	9.7	25.5	100.0	100.0	7.5	7-9
Bulk Sp Gr	2.678	2.716	1.000	2.607	1.000	1.000	1.000	2.900	2.690	2.300	1.000	1.000	2.663	Dust/AB
Absorption, %	1.70	0.90	1.00	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Ratio
												SP GR AB	1.040	0.93

SUMMARY OF SUPERPAVE GYRATORY DESIGN DATA

DATA for N-Int.	8								
	AB, %MIX	Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Pba
MIX 1	7.3	2.151	2.456	12.5	25.1	50.3	12.62	6.10	1.29
MIX 2	7.8	2.168	2.433	10.9	24.9	56.3	14.05	6.74	1.15
MIX 3	8.3	2.171	2.416	10.1	25.2	59.8	15.09	7.23	1.17
MIX 4	8.8	2.197	2.397	8.3	25.1	66.1	16.34	7.77	1.13

DATA for N-des.	50									
		Gmb	Gmm	Voids (Pa)	VMA	VFA	Vbe	Pbe	Gse	Pba
MIX 1	7.3	2.330	2.458	5.2	18.9	72.4	13.67	6.10	2.754	1.29
MIX 2	7.8	2.338	2.433	3.9	19.1	79.5	15.15	6.74	2.744	1.15
MIX 3	8.3	2.342	2.416	3.1	19.4	84.2	16.28	7.23	2.745	1.17
MIX 4	8.8	2.354	2.397	1.8	19.4	90.8	17.59	7.77	2.742	1.13

Hamburg Wheel Information	
Sample No. Passes	20000
Sample Wheel Depth	-1.48

TSR Information	
Conditioned	163.5
Unconditioned	167.8
TSR	0.97
CA Strip Rating	1
FA Strip Rating	1
Additive Prod #	
Additive Product Name	
Additive %	

OPTIMUM DESIGN DATA @ Ndes												
GYRATIONS	AB	Gmb	Gmm	%VOIDS (Pa) Target	VMA	VFA	Gse	Gsb	TSR	RCY AB	Virgin AB	ABR
50	8.0	2.340	2.425	3.5	19.2	81.8	2.745	2.663	0.97	2.4	5.7	29.2

REMARKS LINE 1

REMARKS LINE 2

BITUMINOUS MIXTURE AGED: 1 HOURS @ 305

Lab Preparing Design: PP

Designing Lab Mix#: 81BIT160M

Designing Lab Name: D Const

Tested by:

Reviewed by:

Verified by:

Final Approval: