Laboratory Evaluation of Asphalt Concrete Mixtures from Rt.33 in Rochester, NY

by

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Revised Final Report

September 15, 2004

Introduction

A rehabilitation project on Rt. 33 in Rochester, New York was performed in 2003 by overlaying an existing composite pavement with the STRATA® Crack Relief System and conventional Superpave asphalt concrete mixtures. After one winter, an isolated area of the project showed signs of premature deterioration by what appears to be reflective joint cracking. This area represents about half of the project and is isolated to the west end. The remaining east end of the project had little to no cracking. The total project length is about 11.7 center-lane km (7.3 miles). The project limits are STA 18+900 meters to STA 7+215 meters.

Three cores were taken directly over the apparent reflective cracks and showed that the fracture occurred in the conventional mixes, while the STRATA layer was intact. The locations of cores 1, 2, and 3 represent days 1, 2, and 3 of paving the Strata interlayer, respectively. All cores were from the eastbound lane in the western 2.7 km (1.7 miles) of the project. At this time, the University of Illinois at Urbana-Champaign was asked to perform material characterization tests on cores taken from the pavement.

From a conversation with NYDOT personnel, Koch was informed that some of the Superpave mixtures throughout the state experienced premature surface cracking between December 2003 and February 2004. One explanation for the premature surface cracking could be the climatologic history during this period. Climatologic data collected at the Buffalo, NY NOAA weather station for Rochester, NY shows that the average temperature for January 2004 was -8.2 ^{o}C (17.2 ^{o}F), which was 3.7 ^{o}C (6.7 ^{o}F) below the normal (see Appendix A for the climatologic data). Also, the unofficial low temperature recorded during January 2004 was -24 ^{o}C (-12 ^{o}F), which was the lowest thermal event for the climatologic data reviewed between 1999 and 2004. Using the LTPPBIND, Version 2.1 (1999) and assuming no traffic, the recommended surface Performance Grade (PG) for Rochester, NY was PG 58-28. The design low air temperature was -21 ^{o}C (see Figure 1). The low air temperature for January 2004 exceeded the design low air temperature and may be one of the factors that caused the premature surface cracks.

The pavement section (Figure 2) consisted of the underlying PCC pavement with an existing HMA overlay (~25 mm), STRATA layer (25 mm), truing and leveling (T&L) layer (30 mm), and surface layer (40 mm). The STRATA layer consisted of the cold climate STRATA binder and a mixture design provided by Koch Pavement Solutions. The T&L layer consisted of a 9.5 mm NMAS Superpave mixture with a PG64-28 binder. The T&L layer was used to correct profile prior to placing the surface course and to avoid putting traffic on directly on the STRATA layer. The surface layer consisted of a 12.5 mm NMAS Superpave mixture with 19% Recycled Asphalt Pavement (RAP) and a PG64-28 asphalt binder. The liquid base-asphalt binder for the surface and T&L layers (PG62-28) meets the 98% reliability criteria set forth in the Superpave LTPPBIND design criteria. However, the asphalt binder PG for the surface mixture was not adjusted to account for 19% RAP present in the mixture. NYDOT's current procedures for using RAP follow the recommendations of NCHRP 9-12 – Incorporation of Reclaimed Asphalt Pavement in the Superpave System (McDaniel et al., 2000). If the RAP amount is equal to or greater than 20% of the total mix weight, it is recommended to lower the liquid asphalt binder by one grade, such as lowering from a PG64-28 to a PG64-34 or PG58-34 (depending on traffic). The lowering of the PG should offset the contribution of the stiffer asphalt binder present in the

RAP. The amount of RAP allowed in mixtures without lowering the PG has increased from the original recommendation by the Superpave Mixture Expert Task Group (1997). This former recommendation was to lower the PG one grade if the RAP amount was 16% to 25% RAP. The RAP allowance should be reviewed by NYDOT to adjust for their specific conditions.

NYDOT and Koch Pavement Solutions personnel cored the cracked and non-cracked sections of pavement. The cores taken from the cracked sections showed that the cracks propagated through the surface and T&L layers of the pavement, but arrested at the STRATA layer (Figure 3). Some cores revealed that the PCC base was failing and broken. The cores taken from the intact sections of the pavement were used to investigate the volumetric and material properties of each layer.

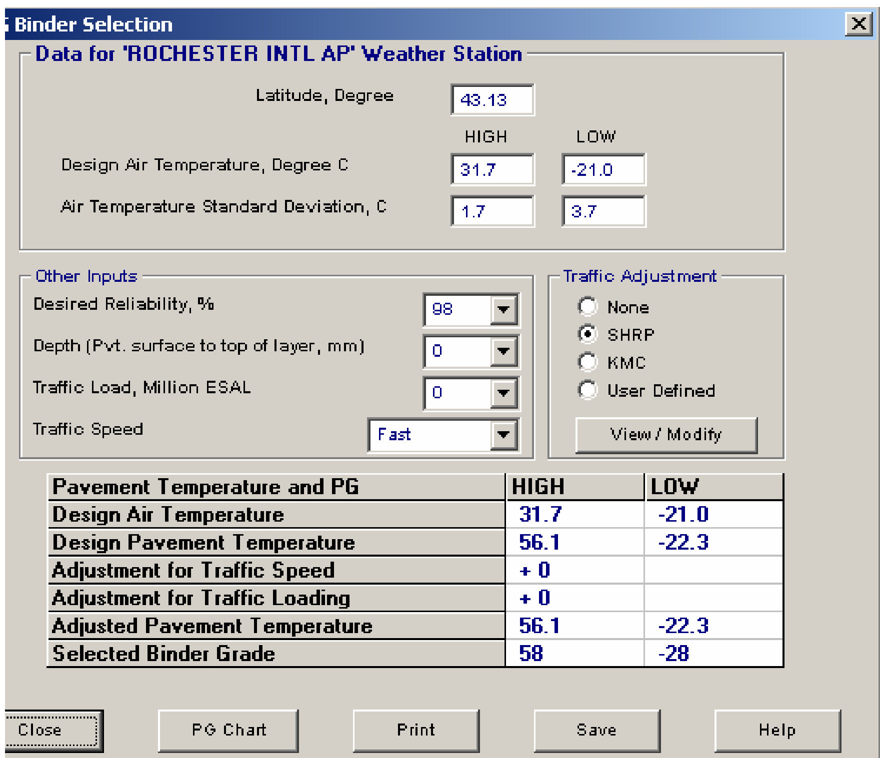


Figure 1 Performance Grade for 98% Reliability Using LTPPBIND and Assuming No Traffic Loading

Surface Layer (12.5 mm)	40 mm
Truing and Leveling (T&L) Layer (9.5 mm)	30 mm
STRATA Layer	25 mm
Existing AC Layer	~25 mm
Existing PCC Pavement	

Figure 2 Cross-Section of Pavement Layers with Thickness

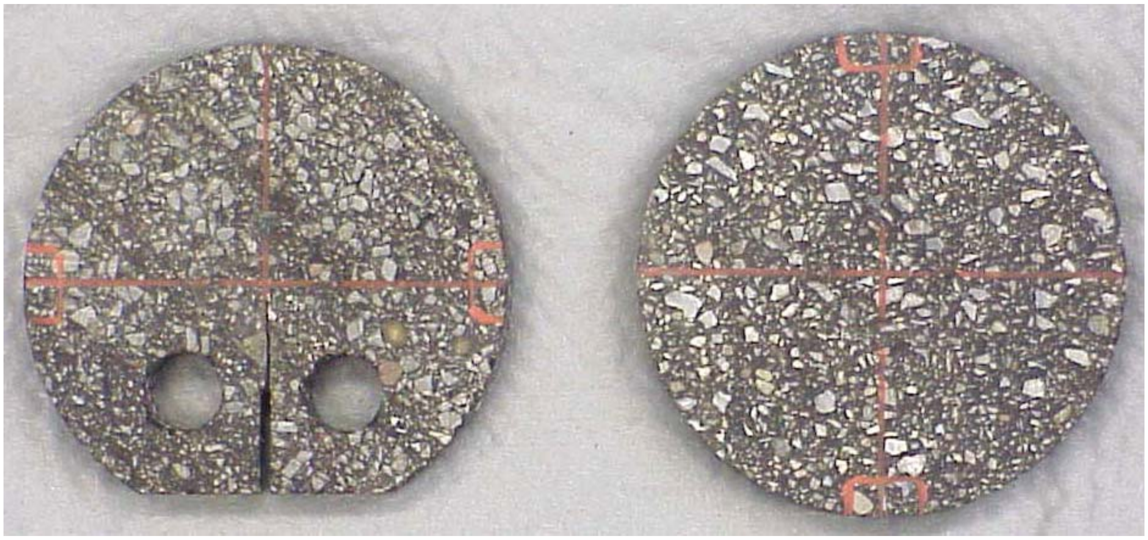
Figure 3 Example of Core Taken from Cracked Section where the STRATA Layer is Still Intact

The following sections will describe the experimental design and testing procedures used in this study. Then the test results will be shown with comparisons among the asphalt mixtures from this section along with mixtures from the University of Illinois database. The final section provides conclusions and recommendations that were drawn from the data.

Experimental Design

The experimental design and test procedures were developed based upon the available material received at ATREL by UIUC researchers. Three 6” diameter cores were cored within close proximity of one other in an intact section of the pavement in Rochester (between the wheel paths, between the reflective cracks). A wet masonry saw was used to cut the cores at the layer interfaces to produce three cylindrical replicates of each mixture type. The existing asphalt mixture, i.e. below the STRATA layer, was not included in the experimental design based on the assumption that the mixture had already failed and was damaged during the construction of the overlay.

The goal of the experimental design was to use the materials available to determine the volumetric properties of the in-place materials (bulk density, % air voids, and aggregate gradations) and to determine the low temperature characteristics of the mixtures, since a factor in the premature failure could be attributed to thermal effects. Two tests were selected to provide low-temperature creep compliance information and low-temperature fracture characteristics of the mixtures. The Superpave IDT test (AASHTO TP-9) was selected to determine the low-temperature creep compliance of the mixtures. The fracture characteristics of the mixtures were determined by a fracture test, the disk-shaped compact tension test (DC(T)), recently developed at the University of Illinois at Urbana-Champaign. The DC(T) test was selected over the more standard IDT strength test because the DC(T) appears to distinguish the temperature sensitivity of the mixture better than IDT strength tests. Based on previous testing experience, the IDT strength test can under predict the strength of compliant mixtures, due localized damage under the IDT loading heads (Al-Khateeb and Buttlar, 2002). The DC(T) specimen geometry was specifically designed for use with cores taken from the field and can be fabricated from existing specimens after IDT creep compliance testing has been completed (Figure 4). The bulk density testing (following AASHTO T-166 Test Method), IDT creep compliance testing, and DC(T) fracture testing were conducted at the University of Illinois at Urbana-Champaign Advanced Transportation and Engineering Research Laboratory (ATREL). Koch personnel conducted the ignition oven and aggregate gradation analysis.



(a) DC(T) Specimen Geometry (b) IDT Specimen Geometry

Figure 4 Comparison of the DC(T) Specimen Geometry (a) and IDT Specimen Geometry (b) Showing the Ability to Fabricate the DC(T) Geometry from the IDT Geometry

Test Procedures for Compliance Testing

The AASHTO TP-9 test method was followed in conducting the creep compliance testing with some added precautions. Based upon the climate and the asphalt binder grade, the test temperatures selected were -30, -20, and -10 ^{o}C. All of the creep loads were applied within 50 to 100 milliseconds and held for 1000 seconds. The 1000-second test duration was used instead of 100 seconds to facilitate more overlap between curves when forming master creep compliance curves. The aforementioned precautions stemmed from the fact that the thickness of the specimens (20-30 mm) was below the optimal thickness (50 mm) typically used with 6" diameter specimens. The thin specimens could have a tendency to bend if any loading eccentricities were present, creating erroneous displacement measurements. Therefore, specimens were carefully aligned within the loading heads to maximize loading symmetry. After temperature conditioning (3 hours at target test temperature), a 5 Hz sinusoidal loading was applied to the specimen to precondition and seat the specimen. The dynamic loading also allowed for observations of the displacements to ensure proper alignment was achieved. Care was taken to ensure that the tensile strain produced by the dynamic loading was less than 100 microstrains at the end of the load cycling (100 cycles). This was also a good indicator for adjusting the creep load to ensure that the tensile strain was under a self-imposed 500-microstrain limit at the end of the 1000-second creep load. The 500-microstrain limit was set to ensure that the specimen was not damaged since the specimen was to be subsequently used for DC(T) testing. With these precautions, the variability in the creep test results was satisfactory.

Test Procedure for DC(T) Fracture Testing

The DC(T) specimen geometry was developed to obtain the fracture energy of asphalt concrete from cylindrical cores taken from field investigations or from laboratory compaction. Work has been ongoing at the University of Illinois on combining advanced numerical analysis with experimental results to develop a better understanding of asphalt concrete fracture (Paulino et al. [2004]). Fracture testing of asphalt concrete has been performed before, but typically with a single-edge notched beam (SE(B)) geometry (Marasteanu et al. [2002], Hossain et al. [1999], Bhurke et al. [1997]). The advantage of the DC(T) geometry is that the geometry allows for a specimen to be fabricated from an IDT specimen (Figure 4). Fracture energy, or the energy required to create a unit area of a cracked surface, has been used before to describe the fracture process of asphalt concrete (Li and Marasteanu [2004]).

With the limited number of replicates available, a single replicate was tested at each of the temperatures used for the IDT testing (-30, -20, and -10 ^{o}C) to develop an understanding of the variation of fracture energy with temperature. The DC(T) specimens were loaded in tension by placing pins through the loading holes. A clip-on gage (Epsilon Model 3541) was attached at the crack mouth to monitor the crack mouth opening displacement (CMOD) and also as the feedback loop for the servo-hydraulic test frame (Instron 8500). The advantage of controlling the test by CMOD is that the fracture process is stable. The CMOD rate was constant at 1 mm/min for all mixtures and temperatures. The fracture energy was obtained by calculating the area under the load-CMOD curve and then normalizing by the ligament length and specimen width.

Results and Discussions

The thickness of each layer was measured after the layers were cut from each core. The layer thicknesses were found to be uniform and close to the design thickness (Table 1), keeping in mind that the thickness of the saw blade was 5 mm. After separating the layers from the cores, the specimens were dried and bulk densities were obtained following the AASHTO T-166 test method (Table 2). The average air voids measured on specimens from field cores for the T&L and surface layers were higher than expected (11% and 8.4% respectively). However, the limited accuracy of air void estimates from thinly sliced field specimens should be considered.

After all testing was completed at ATREL, the specimens were shipped to Koch personnel to perform sieve analysis for obtaining the aggregate gradation of the mixtures. After the ignition ovens, both dry and washed sieve analysis were performed and the average gradation of the three replicates are shown in Table 3 and the results of individual analysis are shown in Appendix B. Correction factors for the ignition ovens results were not available, therefore the in-place asphalt content was not obtained from the field cores. The optimum asphalt content for the STRATA mixture was 8.3%. During the QA procedures, the %AC for STRATA was checked and was reported at 8.3%. For the surface and T&L mixtures, the design optimum asphalt content was 5.2% and 5.8% respectively. There was not any indication that the in-place asphalt content varied significantly from the design optimum for these mixtures.

Table 1 Average Thickness (mm) of Each Layer

	Layer		
Specimen	**STRATA**	**T&L**	**Surface**
1	20.9	24.0	33.1
2	20.4	24.9	33.7
3	21.0	22.9	33.6
Average	20.8	24.0	33.4

Table 2 Bulk Density and % Air Voids for Each Specimen

	Layer					
Specimen	**STRATA**		**T&L**		**Surface**	
	Bulk Density	**% Air Voids**	**Bulk Density**	**% Air Voids**	**Bulk Density**	**% Air Voids**
1	2.294	3.6	2.208	10.4	2.260	8.1
2	2.287	3.9	2.196	10.8	2.256	8.3
3	2.268	4.7	2.189	11.1	2.245	8.7
Average	2.283	4.1	2.198	11.0	2.253	8.4

Table 3 Sieve Analysis (Dry and Washed) for the Mixtures

	STRATA		**T&L**		**Surface**	
Sieve	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
3/4" (19 mm)	100	100	100	100	100	100
1/2" (12.5 mm)	100	100	100	100	99	99
3/8" (9.5 mm)	100	100	100	100	92	93
#4 (4.75 mm)	93	93	86	87	65	67
#8 (2.36 mm)	71	72	54	55	43	45
#16 (1.18 mm)	50	51	36	37	28	29
#30 (0.60 mm)	34	36	24	25	19	20
#50 (0.30 mm)	20	23	13	16	12	16
#100 (0.15 mm)	11	14	7	9	8	11
#200 (0.075 mm)	5.6	9.8	3.5	6.6	4.5	8.4

Creep Compliance

The creep compliance testing at the different temperatures allowed for the development of a master creep compliance curve for each layer tested. The objective for developing the master creep compliance curve was to make relative comparisons of how well the mixtures relax stress over time. A mixture with high creep compliance will relax the stress faster and thus the stress intensity during a thermal cooling cycle will be less, reducing the chance of low-temperature thermal cracking. Three replicates were tested at each temperature and the compliance was calculated following the AASHTO TP-9 test method. Once the compliance tests were completed at each temperature, the master creep compliance curve was formed using standard curve shifting techniques. The master curves (Figure 5) for the three mixtures tested were developed using a reference temperature of -30 ^oC and the Voight-Kelvin model parameters. The STRATA mixture has the higher compliance with an initial compliance two times the compliance of the overlay mixtures and almost 10 times the compliance at long loading times. The compliance for the two overlay mixtures is within a similar range, although the T&L layer was found to have a slightly higher compliance than the surface mixture.

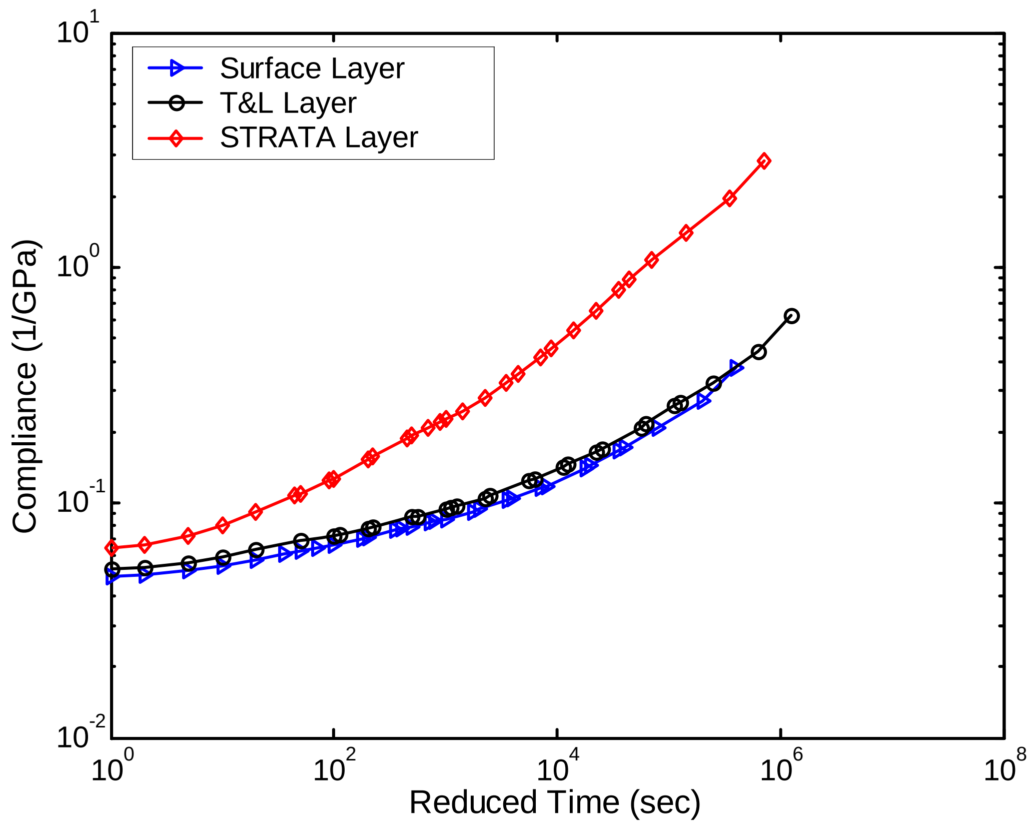


Figure 5 Master Creep Compliance Curves for the Mixtures Placed on Rt. 33, Rochester, NY (T_{ref} = -30 ^oC)

The overlay mixtures from this project were compared to several mixtures with similar asphalt binder properties. To ensure a direct comparison, only the test results from the -20 and -10 ^oC tests were used since all of the mixtures had these two temperatures in common. Figure 6 shows the compliance of six mixtures: the two mixtures from this section (surface and T&L layer), two mixtures from a runway rehabilitation project at the Rantoul National Aviation Center located in East-Central Illinois (PG58-22 and PG64-28), a mixture from I-74 in East-Central Illinois (PG70-22), and a mixture from the MnRoad Project (AC-5, usually comparable to a PG58-28). From this figure, the low temperature properties of the Rochester overlay mixtures are closely grouped with the other mixtures having similar PG low temperature grades

(PGXX-28) and can be distinguished from the mixtures with the PGXX-22 designations (expected to be stiffer at lower temperatures due to the -22 low temperature grade). The scale on this figure allows for a better comparison between the surface and T&L overlay mixtures. The T&L layer with the 100% virgin binder has approximately 50% higher compliance than the surface mixture, which contains 19% RAP.

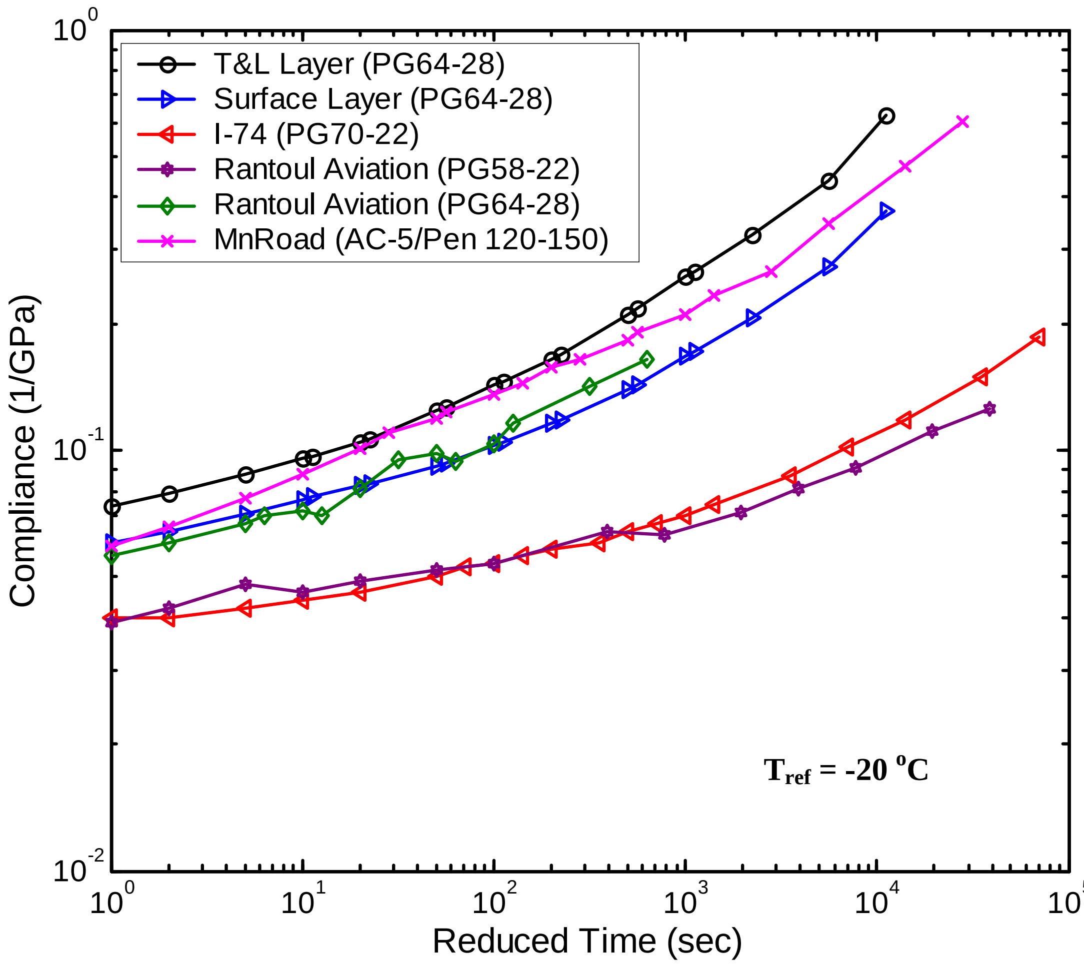


Figure 6 Creep Compliance Comparisons of Typical Mixtures at-20 and -10 ^oC (T_{ref} = -20 ^oC)

Fracture Test Results

After the completion of the creep compliance testing, the specimens were fabricated for DC(T) testing. A single replicate was tested at three temperatures (-10, -20, and -30 ^oC) to determine the fracture performance over a temperature range. The fracture energy obtained for each mixture and temperature is shown in Table 4. The fracture energy of the overlay mixtures

(T&L and surface layers) is comparable at all temperatures, while the STRATA mixture shows significantly higher fracture energy at all temperatures. The fracture characteristics of STRATA are different from the overlay mixtures. Typically, failures can be described using two terms. Brittle failure can be defined as fracture occurring with small deformations, short post-peak softening curve, and low fracture energy. Ductile failure can be defined as large deformations, long softening curve, and high fracture energy. Asphalt concrete failure can transition from a brittle failure at high loading rates and low temperatures to ductile failure at slow loading rates and high temperatures. For the temperatures tested, the STRATA mixture showed a ductile failure at all temperatures, while the overlay mixtures were brittle at the lower temperatures (-10 and -20 ^{o}C). Further evidence of this is exhibited by the crack mouth opening displacements at peak load ($CMOD_{peak}$), which is typically when the crack initiates from the notch tip.

The conventional mixtures showed a small $CMOD_{peak}$ (Table 5), while the STRATA mixture had much higher $CMOD_{peak}$ values, especially at the highest temperature. For the test at -10 ^{o}C, STRATA showed an area of distributed damage at the crack tip (Figure 7) denoted by the distributed cracking. In fact, the STRATA specimen at -10 ^{o}C did not show complete fracture (the crack did not propagate through the specimen). The main reason for this is due to equipment limitations where the CMOD gage only has a range of 6.35 mm and the test exceeded this before the crack could propagate through the specimen. The fracture energy of STRATA at this temperature is not shown in Table 4 because the current analysis does not allow for the determination of the fracture energy when the specimen undergoes large deformations and large area of distributed damage ahead of the crack tip.

Li and Marasteanu (2004) determined that fracture energy could distinguish the difference of the asphalt binder used in the mixture. The study included three asphalt binder types (PG58-XX) with different low temperature performance (-28, -34, -40). The study showed that at low temperatures (-30 and -40 ^{o}C), the fracture energy obtained ranked the mixtures according to the low temperature performance, where the PG58-40 binder had the highest energy due to the more compliant asphalt binder. For the two overlay mixtures, the binder mixture showed increasing fracture energy as the temperature increased, while the surface mixture showed constant fracture energy at -30 and –20 ^{o}C. Again, this points to the fact that the surface mixture contains RAP, which has lowered the compliance and maybe has changed the grade of the asphalt binder.

A recent study conducted at the University of Illinois for the Illinois Transportation Research Center has shown that the inclusion of RAP in a mixture may have more pronounced effects on recovered binder properties than previously expected. For instance, recovered binders from mixtures produced with 19% RAP in Illinois have shown Dynamic Shear Rheometer (DSR) complex moduli (G*) values in excess of 10 kPa immediately after construction, as compared to the desired range of 2.2 to 4.4 kPa for the short-term aging condition (Figure 8). This is in part caused by the extensive variability in RAP properties in Illinois stockpiles, as indicated by the range of values present at 100% RAP (from 6 to 94 kPa). Although these ranges may differ in New York due to differences in climate, materials, and RAP handling practices, it is clear that the presence of 19% RAP in this mixture may have had a significant impact on the final mixture properties. This is particularly important if the base grade of asphalt is not adjusted, as was the case with the surface mix placed on Route 33, Rochester. Often, it would be expected that a softer PG XX-34 binder would be required to produce an effective PG XX-28 binder when RAP (which has stiffer, aged binder) is used in the mixture at a level of 19%.

Table 4. Fracture Energy of Mixtures at -10, -20, and -30 °C

Fracture Energy (J/m^2)

Temperature, °C	Mixture		
	Surface	T&L	STRATA
-10	535	749	--
-20	244	375	2312
-30	249	204	604

Table 5 Crack Mouth Opening at Peak Load for the Mixtures and Test Temperatures

Crack Mouth Opening (mm)

Temperature, °C	Mixture		
	Surface	T&L	STRATA
-10	0.1706	0.1797	3.8206
-20	0.101	0.1291	0.7924
-30	0.0591	0.0801	0.1933

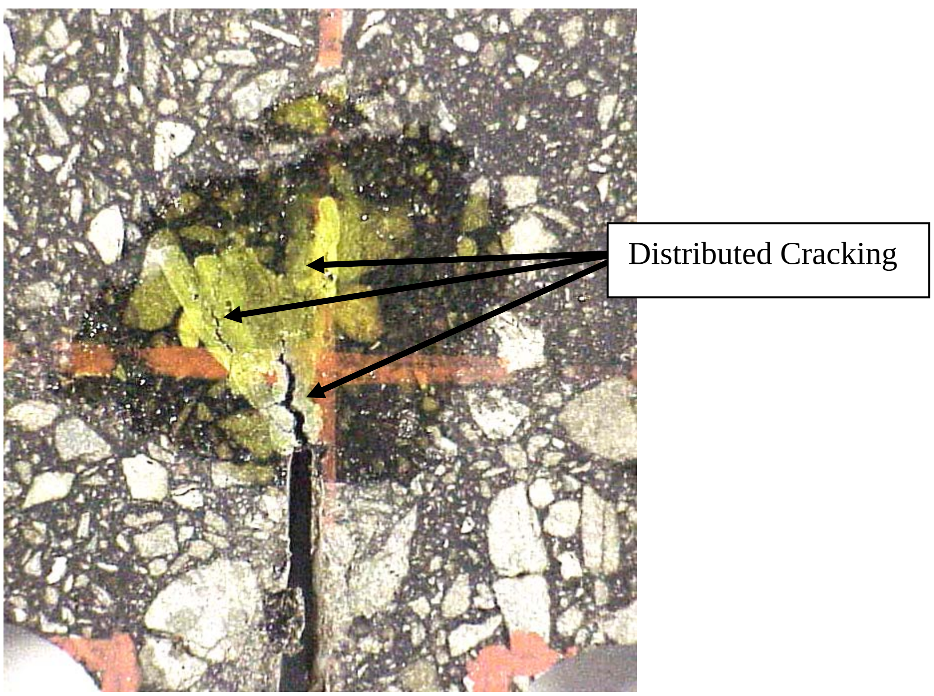


Figure 7 Area of Microcracking in Front of Notch Tip at the End of the Test for STRATA at 10°C

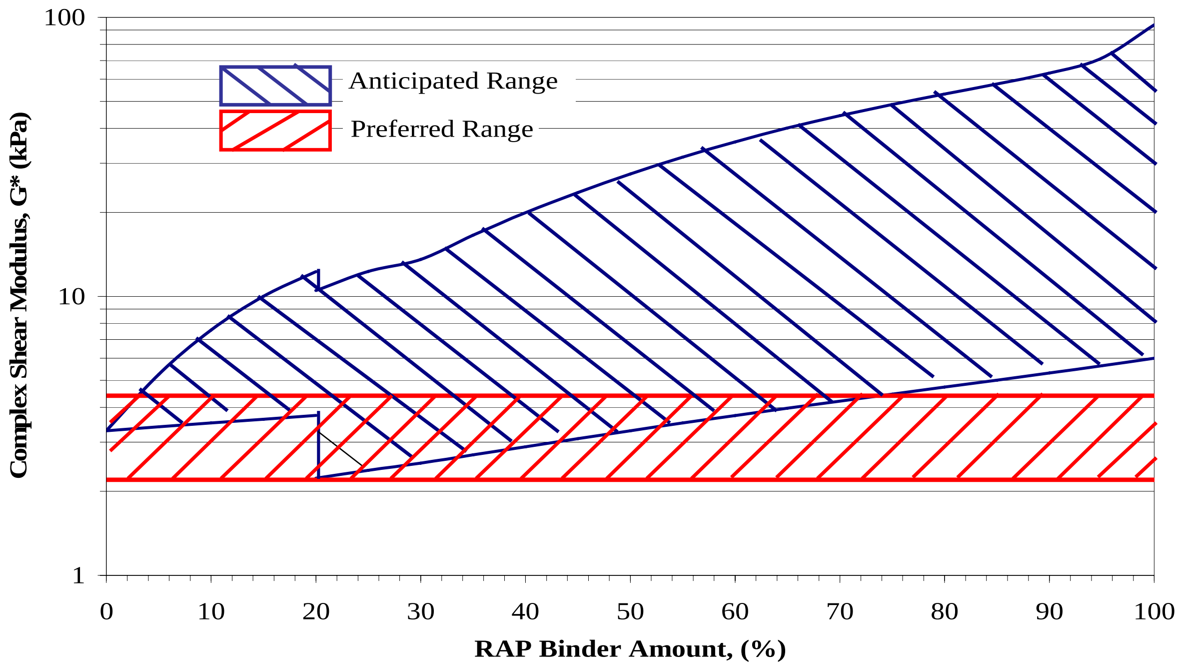


Figure 8 Complex Shear Modulus (G*) versus RAP Amount in Illinois: Preferred Versus Expected Ranges (Compiled using Data From: Buttlar et al., 2004)

The overlay mixtures were compared to two mixtures with a PG64-22 asphalt binder at -10^{o}C (Table 6). The fracture energy of the overlay mixtures was higher at this temperature than the PG64-22 mixtures. The effect of the asphalt binder should influence the energy of the mixtures and this is seen in Table 6.

Table 6 Fracture Energy for Conventional Mixtures at -10^{o}C

Mixture	Fracture Energy (J/m^2)
T&L Layer	749
Surface Layer	535
9.5 mm NMAS (PG64-22)	268
19 mm NMAS (PG64-22)	365

Conclusions and Recommendations

Although the testing reported herein should be considered as tentative, due to the limited availability of testing replicates at this time, the results do point to several areas of concern that might have contributed to the observed cracking failure. These are:

- After a review of the climatologic data, the low air temperature (-24 ^{o}C) during January 2004 exceeded the design low air temperature (-21 ^{o}C) as suggested by LTPPBind Software. Therefore, the premature surface cracking could be related to low-temperature thermal effects. The surface mixture has the lowest compliance and also the lowest fracture energy of all of the layers. Thus, this mixture might possibly be susceptible to thermal events.

- From the testing, the STRATA interlayer has the highest compliance and fracture energy of all of the mixtures tested. The high compliance suggests that the STRATA could relax the stresses induced by the cooling cycle, reducing the stress intensity and susceptibility to fracture. With STRATA having at least 3 times the fracture energy of the overlay mixtures, the overlay mixtures would fracture before the STRATA interlayer if all other factors are constant (displacements due to the cooling cycle).

- The Truing and Leveling (T&L) and surface course mixtures placed above the STRATA layer utilized identical PG 64-28 virgin binders and presumably similar aggregate sources (though they had different aggregate blends and different nominal maximum aggregate size designations). However, these two mixtures exhibited significantly different creep and fracture behavior. This is likely a result of the use of 19% RAP present in the surface course layer. Decreased fracture energy and decreased creep compliance (low temperature cracking resistance) are not a surprising outcome due to presence of RAP. The T&L layer exhibited as much as 50% higher compliance than the surface course layer. Since the tensile creep compliance is driven heavily by the viscoelastic properties of the binder, the differences in aggregate structure between the two mixtures would not be expected to produce this much difference in creep compliance. Similarly, the fracture energy required to fail the T&L mixture was up to 50% higher than that of the surface mixture. It should be recognized that the DC(T) test is relatively new, and that more replicate test specimens are recommended before definitive results can be drawn regarding fracture energy differences.

- The tentative results suggest that the surface mixture is significantly stiffer and more brittle than the T&L mixture at Rochester. The comparison of the surface and T&L mixtures are of the in-place material volumetric properties, i.e. air voids, %AC, etc. To quantify the effects of air voids on these specific mixtures, further testing would need to be conducted to determine if the 3% difference in the air voids would be significant enough to influence the compliance. Typically, mixtures with higher air voids also have higher creep compliance and lower fracture energy. However, it is not known if a 3% difference in air voids would have a significant effect on fracture energy. More extensive testing would need to be conducted to fully understand the effects of mixture volumetric properties on creep compliance and fracture energy to provide for the best performing mixtures under the current pavement conditions.

- The multiple layers with relatively thin lifts could lead to problems at the interfaces of each lift. Thin layers are also more difficult to compact than thicker layers. This can be seen from the higher than normal air voids in the T&L and surface layers. Each interface could be weak point with the possibility of low compaction, poor interface bond, and high stresses. If any of these were present, then this could have caused initiation of a crack.

- The cores that were extracted from the failed section showed that the fracture had occurred in both the surface and T&L layers. As noted previously, the combination of air temperature below the design, low compliance, and low fracture energy could have caused thermal cracking in the surface layer. However, the temperature at the depth of the T&L layer should not have been low enough to exceed the 98% reliability of the mixture. The fracture that occurred in the T&L layer can be attributed to the crack propagation through the surface layer. In this case, the crack tip stress fields were influencing the stress state in the T&L layer, creating high stresses, which could initiate and propagate a crack. At the lower temperatures (-30 and -20 ^{o}C), the fracture energy between the surface and T&L layers was not significant enough to resist the fracturing. The same scenario would occur for the STRATA layer, but the fracture energy of STRATA (7 to 8 times higher than the surface and T&L mixtures at -20 ^{o}C) was high enough to prevent the crack from propagating through the layer. The pavement structure could also contribute to the fracturing of the T&L layer. The joint in the underlying PCC pavement creates a weak plane in the pavement. The joint is opening as the temperature cools down, creating strain and stress in the overlay. If the surface layer cracked from the top due to thermal effects, then the structure becomes more susceptible to contraction. The strain levels in the remaining intact layers (T&L and STRATA) would increase significantly. The energy due to the increased strain levels could exceed the fracture energy of the T&L layer and cause the fracture to occur.

- For follow-up investigation, we would recommend: 1) extraction and recovery of surface course binder to verify in-situ PG binder grade (especially the exact low temperature grade, to the nearest degree Celsius); 2) running the thermal cracking software in the AASHTO Mechanistic-Empirical Design Guide for the surface course mixture and T&L mixture using actual weather data from this past winter in Rochester; 3) additional testing of surface and T&L layers to supplement those tests conducted in this study, primarily DC(T) testing, and; 4) testing cores from the non-cracked areas. Recommendation #1 would help investigate whether or not the use of 19% RAP caused the PG low temperature grade to move significantly higher than -28 C, thereby causing the potential for thermally-induced cracking. Recommendation #2 would further explore this possibility, by testing the actual mixture and predicting its thermal cracking potential. Recommendation #3 would provide more repeatability, particularly given the relatively thin dimensions used in DC(T) tests, and; recommendation #4 would help to determine if the failure was more dominated by the stiffer surface or by a weaker base.

- These first two recommendations listed above would help determine if the cracking at Rochester was likely due to thermal cracking susceptibility of the surface, rather than traditional reflective cracking. The third and fourth recommendations are of lower priority, based upon availability of materials.

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Appendix A

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National Weather Service Forecast Office

Buffalo, NY

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NOTE: The data contained on this page is PRELIMINARY. It may contain errors. Official climate data is available from the National Climate Data Center or the Northeast Regional Climate Center.

Preliminary Local Climatological Data (WS Form: F-6)

Latitude 43° 07' 00" N; Longitude 77° 40' 36" W; Elevation 585'

Station: Rochester NY
Month: January
Year: 2004

Temperature in F							:Pcpn	:Snow		: Wind			:Sunshine		
1	2	3	4	5	6a	6b	7	8	9	10	11	12	13	14	16
Dy	Max	Min	Avg	Dep	HDD	CDD	Wtr	Snw	Dpth	Avg	Spd	Dir	Min	Psbl	Wx
1	37	30	34	8	31	0	0.00	0.0	0	9.4	24	29			
2	49	33	41	16	24	0	0.04	T	0	6.9	16	26			1
3	61	46	54	29	11	0	0.25	0.0	0	11.8	24	25			1
4	46	30	38	13	27	0	0.01	0.1	0	11.2	23	08			
5	31	25	28	3	37	0	0.18	2.2	1	11.0	18	07			1
6	26	11	19	-6	46	0	0.03	0.8	2	14.6	32	26			1
7	19	12	16	-8	49	0	0.01	0.4	2	22.2	33	26			1
8	25	11	18	-6	47	0	0.24	8.1	3	6.8	22	26			2,8
9	11	-4	4	-20	61	0	0.09	3.1	10	7.7	20	01			1,8
10	7	-12	-2	-25	67	0	0.01	0.2	6	5.8	12	27			1
11	28	-2	13	-11	52	0	0.26	4.4	6	13.7	23	23			1
12	33	26	30	6	35	0	0.10	1.5	8	6.8	16	01			1
13	34	2	18	-6	47	0	0.09	1.7	8	18.9	32	32			2,8
14	4	-6	-1	-25	66	0	0.03	1.3	9	8.2	15	08			1,8
15	4	-3	1	-23	64	0	0.12	3.4	10	11.5	26	31			2,8
16	17	-3	7	-17	58	0	0.08	2.5	12	16.9	30	28			1
17	24	5	15	-9	50	0	T	0.5	6	7.2	15	24			1
18	31	18	25	1	40	0	0.17	3.2	5	13.6	24	28			1,9
19	18	13	16	-8	49	0	0.18	4.5	10	15.1	26	29			1,9
20	15	12	14	-10	51	0	0.09	2.5	13	13.3	23	30			1,9
21	21	4	13	-10	52	0	T	0.1	9	9.2	16	20			1
22	28	8	18	-5	47	0	0.06	1.7	8	18.7	36	25			1,9
23	14	6	10	-13	55	0	T	T	9	16.4	28	26			8
24	10	2	6	-17	59	0	0.05	2.4	6	10.7	22	31			1,8,9
25	12	-4	4	-19	61	0	T	T	7	4.9	12	22			1
26	13	5	9	-14	56	0	0.05	1.5	6	13.3	21	09			1,9
27	32	13	23	0	42	0	0.35	4.6	8	13.0	21	12			1,6,8
28	26	20	23	0	42	0	0.10	3.2	12	18.0	29	25			1,9
29	21	11	16	-7	49	0	0.01	0.5	15	21.4	33	25			1,8
30	17	9	13	-10	52	0	0.02	0.6	15	22.2	32	25			1,8,9
31	20	14	17	-6	48	0	0.19	6.3	10	13.9	24	27			1,9
Sm	734	332		-199	1475	0	2.81	61.3		394.3					
Avg	23.7	10.7	17.2							12.7					

Notes:

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Column 17 Peak Wind in M.P.H.
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Preliminary Local Climatological Data (WS Form: F-6) , Page 2
Station:   Rochester NY
Month:     January
Year:      2004

Temperature Data       Precipitation Data        SYMBOLS USED IN COLUMN 16

Average Monthly: 17.2   Total for Month:  2.81     1 = FOG
Dptr fm normal:  -6.7   Dptr fm normal: 0.47       2 = FOG REDUCING VISIBILITY
Highest:  61 on     3   Grtst 24hr 0.40 on 27-28       TO 1/4 MILE OR LESS
Lowest:  -12 on    10                              3 = THUNDER
                        SNOW, ICE PELLETS, HAIL    4 = ICE PELLETS
                        Total month:  61.3         5 = HAIL
                        Grtst 24hr   8.1  on    8  6 = GLAZE OR RIME
                        Grtst depth: 15 on 30      7 = BLOWING DUST OR SAND
                        Seasonal Total:  93.9          VSBY 1/2 MILE OR LESS
                                                   8 = SMOKE OR HAZE
 No. of Days with        WEATHER - Days with       9 = BLOWING SNOW
                                                   x = TORNADO

Max 32 or below: 25     0.01 inch or more: 26
Max 90 or above:  0     0.10 inch or more: 11
Min 32 or below: 29     0.50 inch or more:  0
Min  0 or below:  7     1.00 inch or more:  0

 HDD (Base 65)
Total this Mo. 1475
Dptr fm normal  212
Seasonal total 3785
Dptr fm normal   49

 CDD  (Base 65)
Total this Mo.    0
Dptr fm normal    0             Pressure Data
Seasonal total    0      Highest SLP 30.55 on 10
Dptr fm normal    0      Lowest  SLP 29.51 on 18
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National Weather Service
Weather Forecast Office Buffalo
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Page last generated: February 1, 2004 at 06:24:55 AM

Appendix B

Table B1. Sieve Analysis for STRATA

Dry Gradation After Ignition				Sieve	Wet Gradation After Ignition			
Sample #1	Sample #2	Sample #3	Average		Average	Sample #1	Sample #2	Sample #3
100	100	100	100	**3/4**	100	100	100	100
100	100	100	100	**1/2**	100	100	100	100
100	100	100	100	**3/8**	100	100	100	100
91	94	93	93	**#4**	93	93	93	93
70	73	71	71	**#8**	72	72	71	71
49	51	50	50	**#16**	51	50	51	51
34	35	34	34	**#30**	36	35	36	36
19	23	20	20	**#50**	23	24	24	22
10	12	10	11	**#100**	14	14	15	14
5.1	6.4	5.2	5.6	**#200**	9.8	9.6	10.1	9.7

Table B2. Sieve Analysis for the Truing and Leveling (T&L) Layer (9.5 mm NMAS)

Dry Gradation After Ignition				Sieve	Wet Gradation After Ignition			
Sample #1	Sample #2	Sample #3	Average		Average	Sample #1	Sample #2	Sample #3
100	100	100	100	**3/4**	100	100	100	100
100	100	100	100	**1/2**	100	100	100	100
100	100	100	100	**3/8**	100	100	100	100
85	88	86	86	**#4**	87	85	88	88
53	55	54	54	**#8**	55	53	55	56
36	36	36	36	**#16**	37	37	37	38
24	24	24	24	**#30**	25	25	25	25
13	14	13	13	**#50**	16	15	15	18
7	7	7	7	**#100**	9	9	9	10
3.5	3.5	3.5	3.5	**#200**	6.6	6.3	6.2	7.4

Table B3. Sieve Analysis for Surface Layer (12.5 mm NMAS)

Dry Gradation After Ignition				Sieve	Wet Gradation After Ignition			
Sample #1	Sample #2	Sample #3	Average		Average	Sample #1	Sample #2	Sample #3
100	100	100	100	**3/4**	100	100	100	100
100	99	99	99	**1/2**	99	100	98	100
91	92	92	92	**3/8**	93	93	94	92
66	65	65	65	**#4**	67	68	66	66
44	43	44	43	**#8**	45	46	44	44
28	27	28	28	**#16**	29	30	29	28
19	18	19	19	**#30**	20	20	20	20
13	12	13	12	**#50**	16	17	16	14
8	7	9	8	**#100**	11	12	11	11
4.3	3.9	5.3	4.5	**#200**	8.4	8.8	8.2	8.2