Evaluation of Small Top Size Superpave Mix for Ultra Thin Overlays

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ABSTRACT: Superpave asphalt mixture with a small top size (4.75-mm Nominal Maximum Aggregate Size, NMAS) is promising for low-cost pavement maintenance treatment. This paper discusses performance of 4.75-mm NMAS field and laboratory mixes in Kansas as ultra-thin overlays. Six test sections were constructed on two rehabilitation projects in Kansas with variable rates of tack coat application. Cores were collected from each test section two to three months after construction for Hamburg Wheel Tracking Device (HWTD) tests. Rut tests were also performed on 4.75-mm NMAS laboratory mixes with two different aggregate gradations incorporating three different natural sand contents and two different binder grades. Test results on the field cores show that rutting observed during HWTD tests is dependent on the in-place density of the compacted mixture. The effect of tack coat application rate on the rutting performance is insignificant. However, rutting performance of the laboratory mixes is significantly affected by the natural sand content. Laboratory pull-off tests on field cores show that most cores are fully bonded at the interface of the ultra-thin overlay and the underlying Hot-in-Place Recycle (HIPR) layer regardless of the tack application rate. Some partial debonding happened only on the higher tack coat section on one project. Lower natural sand content resulted in improved rutting performance of laboratory mixes. Binder grade did not appear to affect the mixture performance appreciably. The small top size mixture reduces road roughness considerably.

KEY WORDS: Tack coat , 4.75-mm NMAS Superpave mixture, rut test, bond strength.

1 INTRODUCTION

Ultra-thin hot mix asphalt (HMA) overlays have the potential to improve ride quality and safety characteristics, extend pavement life, increase durability, and reduce permeability and road-tire noise. Many states, including Kansas, are looking at less costly pavement preservation techniques due to budget constraints. Past experiences with ultra-thin overlays were good in a few states. However, since the layer is so thin, potential scuffing and gouging of this mix was a real concern in Kansas. This study was initiated to research rutting performance and bond strength of the ultra-thin overlay layer incorporating 4.75 mm NMAS Superpave mix.

1.1 Superpave Fine-Mix Application and Tack Material

The departments of transportation in Georgia and Maryland have successfully used thin hot-mix asphalt (HMA) overlays as part of their preventive maintenance program. North Carolina also successfully implemented thin-lift overlay consisting of coarse sand asphalt mix for very low-volume roadways. Other states, such as Ohio, Missouri, Indiana, and Tennessee, also have their own specifications for thin-lift HMA applications. Ohio uses a mixture known as "Smoothseal." Type A of this mix is extremely fine and is used for medium and urban traffic. Type B is a coarser mix and is used for heavy-duty traffic and high-speed applications. Type B gradation is similar to that of the 4.75-mm NMAS Superpave mixture (Cooley et al. 2002). Recently many state agencies have expressed an interest in implementing 4.75-mm NMAS Superpave-designed mixtures for thin-lift applications, leveling courses, and roadway maintenance. This can be seen in results of a nation wide survey of state highway agencies conducted by the National Center for Asphalt Technology (NCAT) (West and Rausch 2006). Another important issue for ultra-thin-lift overlay is the bond strength at the interface layer. Various studies have been done on tack–coat application rate and bond strength (Mohammad et al. 2001; Mrawira and Yin 2006; Tashman et al. 2006; Yildirim et al. 2005; West et al. 2005 Wheat 2007).

2 PROBLEM STATEMENT

Potential limitations of small aggregate-size mixtures include concerns with permanent deformation, moisture resistance, scuffing, gouging, and skid resistance. In addition, before 2002, gradation criteria followed by different state agencies were different and were developed based on local experiences. In 2002, the 4.75-mm NMAS designation and criteria were added to the AASHTO Superpave specifications to fit the need for small aggregate-size mixtures. These criteria were based on a combination of experience, limited laboratory research, and engineering judgment. Thus, no study has been reported on the large-scale use of this mix in the field. Proper tack coat application rate is another vital issue to obtain optimum bond strength between this layer and the existing layer. To date, no field study has been performed on bond strength of ultra-thin overlays with 4.75-mm NMAS mixtures.

3 OBJECTIVE

The primary objective of this research was to evaluate performance of ultra-thin, 4.75-mm NMAS Superpave mix overlays at different residual tack coat application rates. Performance was examined based on interface bond strength tests and permanent deformation of the Superpave layers with different residual asphalt from tack materials at the interface. In addition, permanent deformation of the 4.75-mm NMAS mixes in the laboratory was also assessed.

4 TEST SECTIONS

Two rehabilitation projects on US-160 and K-25 were overlaid with 4.75-mm NMAS Superpave mixture in 2007. Annual Average Daily Traffic (AADT) varied from 625 to 1,398 and 423 to 488 in 2006 on US-160 and K-25, respectively. The 20-year, design-equivalent, single axle loads (ESAL) for the overlay were 1.7 millions and 1.5 millions on US-160 and

K-25, respectively. Three test sections with variable tack coat application rates were set up on each project. Test section lengths on US-160 and K-25 were 36.5 m and 61 m. The 4.75-mm NMAS Superpave mixture overlay thicknesses on US-160 and K-25 were 15 mm and 19 mm, respectively. During construction, slow-setting low viscous emulsified asphalt (SS-1HP) was applied at three different residual application rates: low (0.054 l/m^2), medium (0.11 l/m^2), and high (0.22 l/m^2). The tack coat application temperatures were 77^0 C and 79^0 C on K-25 and US-160, respectively. Tack coat application rates were set based on the current KDOT's specifications (0.18 l/m^2 diluted tack coat application rate). The SS-1HP tack material was allowed to set for approximately two hours before paving operation. After the tack coat sections were set up, normal pavement construction practices were followed, which included HMA haul trucks backing over the tacked surfaces.

4.1 Field Core Collection

Four 150-mm diameter cores were collected along the right wheel path from each test section one month after construction. The cores were cut to a height of 62 mm for making specimens for tests in the Hamburg Wheel Testing Device (HWTD). The size (height and diameter) satisfied the requirements of Tex-242-F, the standard test method of the Texas Department of Transportation (TxDOT) that was followed in this study (PMW 2009). Bulk specific gravity (G_{mb}) and maximum specific gravity (G_{mm}) were also determined in the lab to assess in-place density. Approximately 51-mm diameter cores in the second phase were collected in June 2008, one year after paving and traffic operation along the right wheel path on each test section. The collected cores were cut to a height of 51 mm to perform pull-off tests. The test specimens contained only 15 mm to 19 mm of 4.75-mm NMAS overlay. The rest were HIPR layer with tack coat at the interface.

5 4.75-mm NMAS SUPERPAVE MIXTURE in LABORATORY

Currently 4.75-mm NMAS Superpave mixture is designated as SM-4.75A in Kansas. Required mixture design criteria are shown in Table 1. Most requirements are similar to those for other sizes except higher dust-to-effective binder ratios.

The AASHTO standard practice (R 35-4), *Superpave Volumetric Design for Hot-Mix Asphalt (HMA)*, was followed during the mix design phase of this study (AASHTO 2004). R 35-4 was used to evaluate the 4.75-mm mixture properties following KDOT volumetric specifications for SM-4.75A mix. The project mix design for 4.75-mm NMAS used 35% natural sand. Twelve mixes with two different binder grade (PG 64-22 and PG 70-22) and three natural sand content (35%, 25% and 15%) were developed in laboratory for both US-160 and K-25 project. Four trial aggregate blends were developed satisfying Kansas gradations for SM-4.75A mixture. Control points for the 4.75-mm sieve (100-90% passing) were strictly observed in the blending process to maintain a true 4.75-mm NMAS mixture. Figure 1 shows gradations developed in this study.

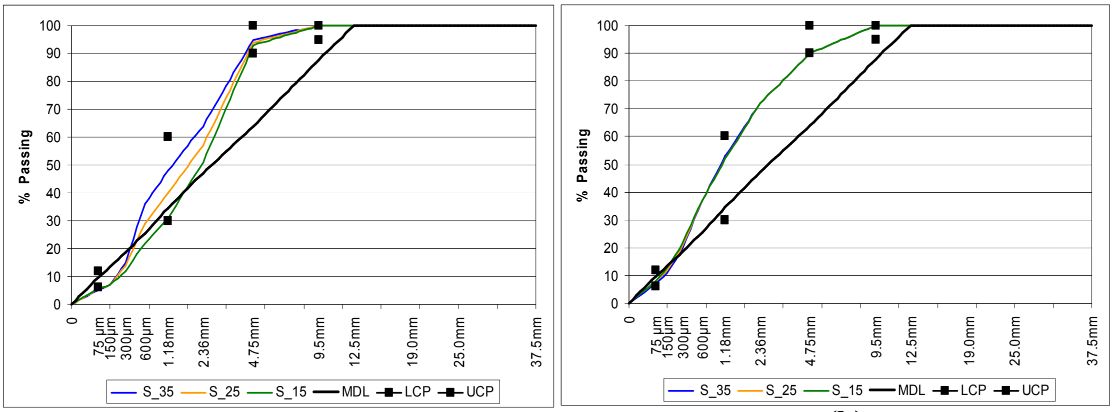
6 PERFORMANCE TESTS ON FIELD AND LABORATORY SAMPLES

6.1 Hamburg Wheel Tester Rutting Evaluation (PMW 2009)

Permanent deformation of the HMA overlay and laboratory mixes was evaluated using the Hamburg Wheel Tracking Device (HWTD). The test measures the depression and number of wheel passes to failure (20-mm rut depth). Figure 2 shows the HWTD test setup and failed samples from the US-160 project.

Table 1: Mixture design criteria for Kansas 4.75-mm NMAS mixtures (Hossain et al. 2009)

Criteria	**Specifications**	**Comments**
	Compaction Effort	
N_{ini} N_{des} & N_{max}	Function of 20-year design ESALs	Similar to other Superpave mixes
	Volumetric Properties	
Air voids	4% ± 2% at N_{des}	Similar to other Superpave mixes
VMA	16% min. for reconstruction/major modification project	may be reduced by 1% for 1-R jobs
VFA	65-78	20-year design ESALs
%G_{mm} @ N_{ini}	90.5	Function of 20-year design ESALs and layer depth
%G_{mm} @ N_{max}	98.0	Similar to other Superpave mixes
dust-to-binder ratio	0.9 to 2.0	0.6-1.2 or 0.6-1.8
Tensile Strength Ratio, min. (%)	80	80



(a) **(b)**

Figure 1: 0.45 power charts for 4.75-mm NMAS laboratory mixture (a) US-160 and (b) K-25

Figure 2: Experimental set-up and failure surface on field cores

HWTD is an electronically powered device capable of moving a steel wheel with a diameter of 204 mm and width of 47 mm over a test specimen. The load applied by the wheel is approximately 705 ± 22 N, and the wheel passes over the test specimen approximately 50 times per minute. The water control system of HWTD is capable of controlling the test temperature from 25 to 70^0C, with a precision of $\pm 2^0$C. The rut-depth measurement system consists of a linear variable differential Transformer (LVDT) device. Rut depth is taken after every 100 passes of the wheel. TxDOT specifications allow 20,000 wheel passes and 20 mm rut depth (which-ever comes first) as failure criteria to evaluate rutting performance of mixtures.

6.2 Pull-Off Tests for Bond Strength Measurement

The American Society of Testing and Materials (ASTM) standard test, "Standard Test Method for Pull-Off Strength of Coating Using Portable Adhesion Tester" (ASTM 2003). The test measures the tensile force required to pull apart two bonded flat surfaces. The test result can be reported either as pass/fail or by recording tensile force to split the bonded layer.

Figure 3: Pull-off strength test of tack coat material

KDOT has partially adopted this test procedure to evaluate in-situ bond strength in the field. During this study, the KDOT procedure was followed with a SATEC model T 5000 universal testing machine. Before testing, both faces of a core were glued to metal plates using epoxy (Pro-Poxy 300 fast A/B). The epoxy needed 16 to 24 hours to set and to make perfect bonding with the bituminous mixture. The strength test was performed at 25^0 C. During testing, the core samples were conditioned under normal loads of 0 to 4.5 kg for five seconds. The applied displacement was set to 25 mm/minute. The test samples were then loaded to fail in direct tension (Figure 3).

7 ANALYSIS AND RESULTS

7.1 Rutting Performance of Field Cores

HWTD was used to perform rut tests on all six sets of cores. Four cores from each test section (low, medium, and high tack application rate) were used to make the HWTD samples. Air voids of the field cores were determined from results of the maximum theoretical specific gravity (G_{mm}) and bulk specific gravity (G_{mb}) tests. On the US-160 project, air voids of the cores varied from 6.6% to 8.6%, while K-25 sections had a mean air void of 4.3%. Air voids of the K-25 field cores were much lower than those for the US-160 cores. However, US-160 cores carried a higher number of wheel passes before failure (19 mm rut depth) as shown in Figure 4. The highest number of wheel passes was observed on the low tack application rate sections on US-160. There was no appreciable difference in the number of wheel passes for the medium and high tack application rates.

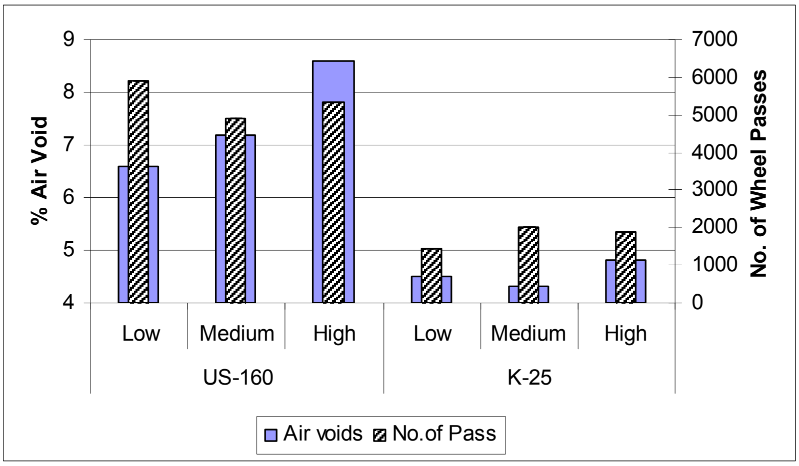


Figure 4: Rutting performances of field cores on US-160 and K-25

HWTD results showed that the number of wheel passes significantly increased at in-place density near 93%. These results also implied that compaction during paving is one of the major factors controlling performance of the mix. Cores from K-25 project experienced excessive rutting and stripping during the HWTD test due to overcompaction at very early age of the pavement. The US-160 mixture contained anti-stripping additive which may significantly influence rutting performance in submerged condition in HWTD.

7.2 Pull-Off Tests on Field Cores

Results obtained in the pull-off strength test in this study are shown in Figure 5. In most cases, on both projects, tensile failure occurred within the HIPR layer material and/or surface material, rather than at the interface. Results from US-160 implied that complete bonding was achieved between these layers, regardless of tack coat application rate. However, test section with higher tack coat experienced higher percentage of failure within the HIPR layer.

On K-25, partial bond failure (PBF) occurred for some cores from the test section with high residual tack coat application rate while only one core from medium tack rate failed. Test results showed that the HIPR layer materials were weaker compared to the overlay mixes. Approximately 57% of the total failure occurred in HIPR, 26% failure in surface material and 17% at the interface of these two. However, 43% of the field cores from the test section with higher tack coat application rate had partial debonding at layer interface. This finding was notably important as it implied that the high tack application rate might be too high to provide sufficient bond strength for the overlay. Another significant finding was that bond strength at the HMA interface is highly dependent on the aggregate source and volumetric mix design of the adjacent layer material.

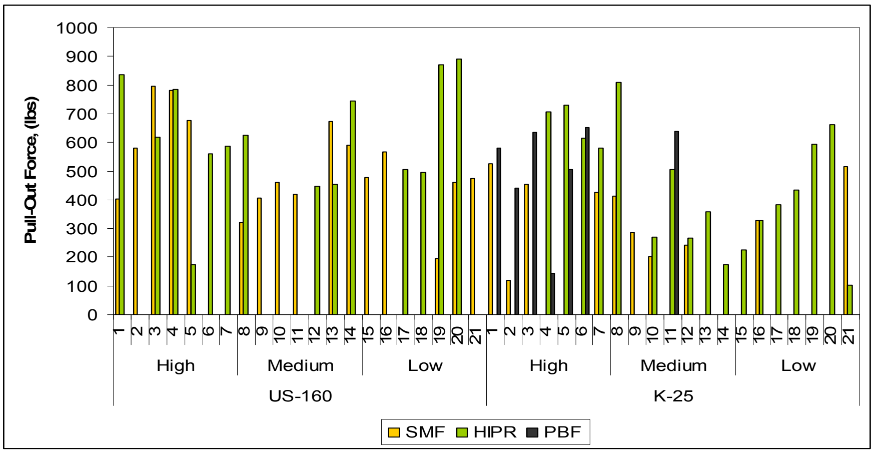


Figure 5: Pull off strength at different residual tack coat application rates on US-160 and K-25

7.3 Rutting Performance of 4.75-mm Laboratory Mixes

HWTD was used to evaluate rutting and stripping performance of all 12 mixes. Three replicates were made for a particular mix design to obtain unbiased test results. The specimens had air voids of 7±1% and were tested at 50^0 C. The test was continued till 20 mm rut depth or 20,000 wheel passes whichever came first.

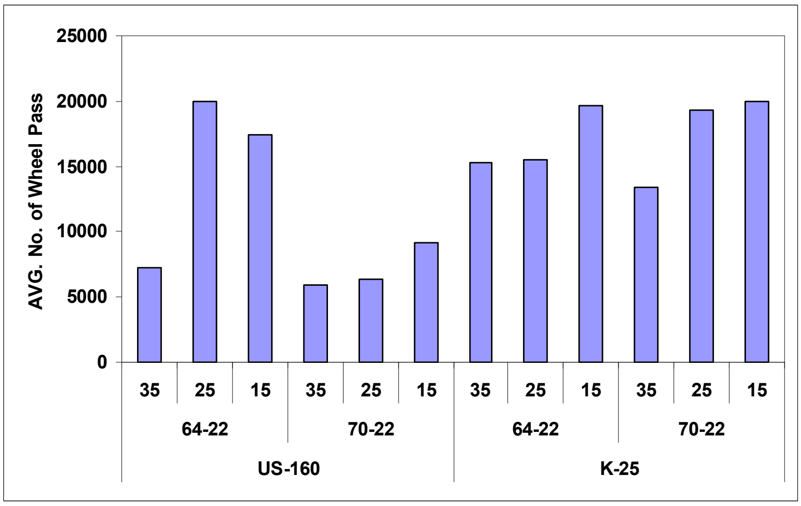


Figure 6: Rutting performances of 4.75-mm NMAS laboratory mixes

Figure 6 shows the average number of wheel passes obtained during this test. The result shows that natural sand content was an important factor affecting rutting performance of laboratory mixes. In general, the number of wheel passes increased with decreasing natural sand content. Also, mix performance was aggregate source specific. In most cases, there is no significant difference between the performance of the mixes with 25% and 15% natural sand. Binder grade did not appear to affect the mixture performance appreciably. The performance of mix with PG 70-22 binder grade on US-160 was notably different than that of mix with PG 64-22. The number of wheel passes was significantly lower during HWTD testing. Further investigation was performed to evaluate the effect of anti-stripping agent on binder grade. Table 2 shows the test results on binder grade PG 70-22. Further investigation was performed to evaluate the effect of anti-stripping agent on binder grade. It was found that the anti-stripping agent did not have any significant effect on the binder properties except on the long term aging performance. The stiffness of the binder reduced almost 50% after adding the liquid amine. The test results also proved that the original binder PG 70-22 was not acid-modified.

Table 2: Verification of binder grade with/without anti-stripping agent

Binder Grade	**Original Binder**	**RTFO[1]**	**PAV[2]**		**Binder Grade (after aging)**
	$G^*/\sin\delta$ kPa[3]	**$G^*/\sin\delta$ kPa[3]**	**$G^*\times\sin\delta$ kPa[3]**	**m @-12^0 C**	
PG 70-22 (without Anti-stripping)	1.12	2.64	2965	0.324	70-25
PG 70-22 (with Anti-stripping)	1.18	2.66	1543	0.385	71-28

[1] RTFO = Rolling Thin Film Oven; [2] PAV = Pressure Aging Vessel; [3] 1 kPa = 0.145 psi

8 FIELD PERFORMANCES

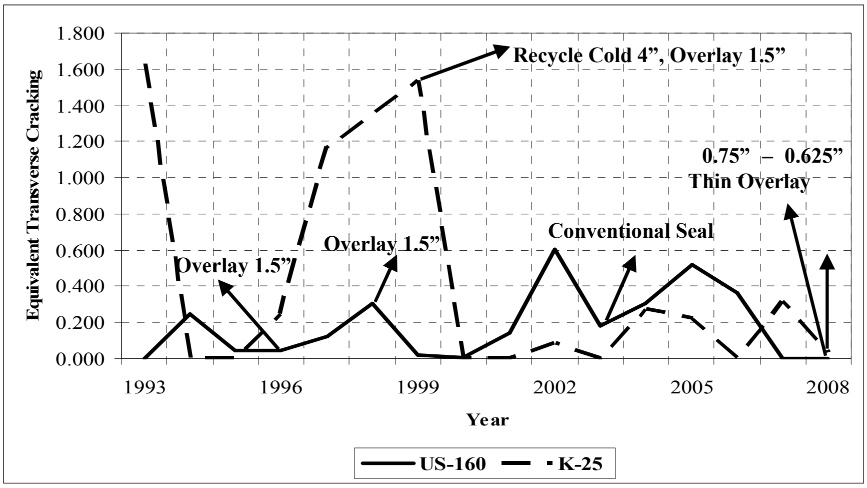
8.1 Performance History of the Test Section

Figure 7(a), (b), and (c) show the performance history of the projects. The HIPR and overlay resulted in remarkable improvement in roughness (about 24% decreases in roughness). Overall, US-160 was smoother than K-25. The rutting (2.54 mm to 3.8 mm) was fully addressed. K-25 had transverse cracking and that was also addressed by HIPR and overlay. However, a cursory survey in 2009 has indicated that transverse cracks are returning on this project. US-160 seems to be doing fairly well. The scuffing and gouging of these mixtures were real concerns. Both projects showed these issues were unfounded.

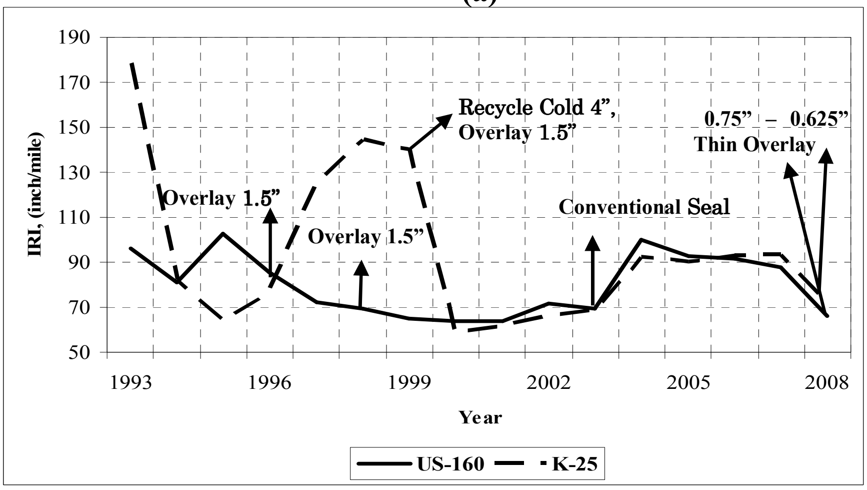
9 CONCLUSIONS

Based on this study, the following conclusions can be made:

- During pull-off testing, most failure occurred within the 4.75-mm NMAS overlay and with HIPR materials, rather than at the interface. This implied that the overlay layer was fully bonded with the HIPR layer in most cases. However, the high tack application rate used in this study might be too high to provide sufficient bond strength for the overlay.
- Rutting performance was project-specific and was highly dependent on in-place density of the compacted mixture, rather than the tack application rate. Lower natural sand content results in better rutting performance in the laboratory tests. Higher binder grade may or may not improve rutting performance of these mixes.
- Performance history on the K-25 project showed that this mixture should not be used in an ultra-thin overlay with one inch HIPR. Crushed gravel aggregates seemed to be better in the mixture than the crushed limestone aggregates. A higher grade binder (PG 70-22 instead of PG 64-22) may be needed to address the transverse cracking issues.



(a)



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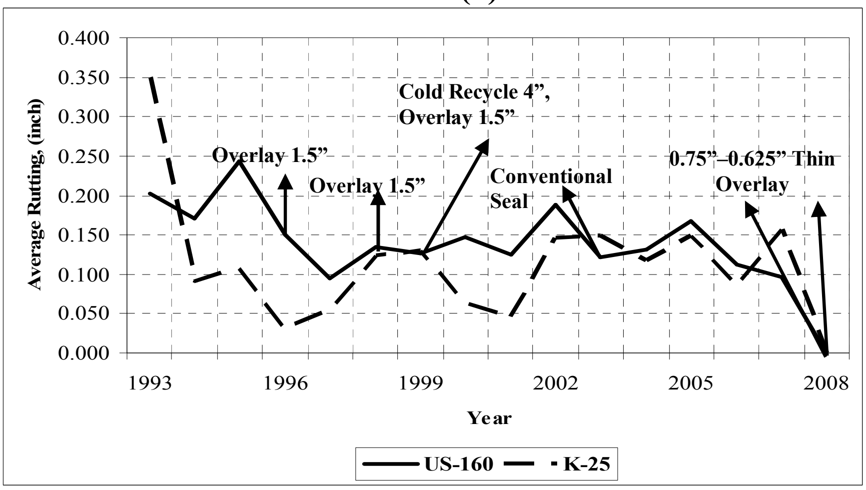

(c)

Figure 7: (a) Transverse cracking, (b) IRI, and (c) rutting progression on US-160 and K-25 during 1993-2008

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