# Accelerated loading test results of two NCAT sections with highly modified asphalt


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## Abstract

In a jointly executed program Delft University of Technology in The Netherlands and Kraton Polymers have developed a new generation of SBS modified asphalt binders that allow construction of thinner and more durable pavements. To validate the findings from these studies, Kraton Polymers committed to a field trial in 2009 at the National Center for Asphalt Technology (NCAT) in Auburn, Alabama, United States. A highly modified asphalt base course at reduced thickness is compared to a standard base course under heavy truck loading.

As a result of the good performance of the first section, the opportunity arose to pave another section at NCAT in August 2010. An adjacent section needed urgent repair as high deformations in the subgrade lead to severe cracking of the asphalt. A highly modified, fatigue resistant overlay mix was paved over the cracked base.

In this paper the latest results are given of the two full scale test sections for highly modified asphalt pavements at NCAT.

## 1. Introduction

The increase of traffic intensities and pavement loadings and the reduction of agency budgets drive the need for better pavement structures with a lower life cycle cost. SBS modified bitumen is an established product in the Australian market that has proven to improve permanent deformation resistance and durability in wearing courses. Use of SBS in intermediate and base courses has been limited due partly to the perception that base courses, with narrower temperature spans than surface courses, do not need modification. However, the study that was done at Delft University of Technology in The Netherlands has demonstrated that the ability of SBS polymers to resist fatigue cracking can be used to reduce the overall thickness of a flexible pavement. This is being validated at the National Center for Asphalt Technology (NCAT) in Auburn, Alabama, USA with very good results until date.

This paper provides information of two projects at NCAT:

- Correlation of a highly modified, thinner structural section rut depths at NCAT with APA and AMPT Flow Number results and finite element modeling results
- Highly modified rehabilitation of a failed “perpetual pavement” section and visual observation after twelve months of the section

## 2. Concept of Highly Modified Asphalt

The concept of highly SBS modified asphalt pavements is comprised of highly fatigue resistant asphalt layers by using very tough binders. These binders derive their fatigue resistance from a continuous polymer rich phase. To get these properties throughout the asphalt pavement the lower asphalt layers also need to be SBS modified. This is not widely done at this time and therefore the focus of the study with Delft University of Technology (prof. dr. ir. A.A.A. Molenaar) was put on testing highly modified asphalt base courses.

In base courses one is seeking a relatively high stiffness, which, next to the mix design, is achieved by choosing relatively hard bitumen. These asphalt mixes result in a certain fatigue resistance, which then determines how thick the pavement will be designed in order to achieve a certain minimum lifetime. This means that roads carrying a high traffic load have relatively thick base courses. However, if one were to produce a base course with a binder that has at the same stiffness a much better fatigue resistance, the layer thickness can be reduced. This will save natural resources, and, if the improvement and thus the layer thickness reduction is significant enough, lead to a cost saving up front.

This situation of high toughness in PMB is achieved at concentrations > 6% SBS and the combination of this high content and the relatively hard base bitumen to be used, creates an issue with compatibility and workability of the asphalt mix. This issue has been addressed with the newly developed high vinyl grades. These polymers have the ability to create in-situ compatibilisation with the bitumen, while maintaining low viscosities.

More information about the concept and the lab testing and modeling work can be found in [1, 9].

## 3. Background on field trials at the National Center for Asphalt Technology (NCAT)

### 3.1 Objective and scope

The primary objective of the field trials at NCAT is to evaluate the in situ structural characteristics of a highly (polymer) modified asphalt (HiMA) pavement relative to a control section under the same traffic and environmental conditions.

In 2009 a section was paved using a highly SBS modified binder in all three HMA layers. This section has been monitored since then. In parallel a laboratory evaluation takes place which includes characterization of the mixes in terms of binder, rutting, fatigue, and moisture susceptibility performance.
In this paper rutting resistance results from the field section are compared with Asphalt Pavement Analyzer (APA), Asphalt Mixture Performance Tester (AMPT) and finite element modeling results.

The highly modified overlay of section N8 was paved in summer 2010. The design of this section and visual performance observations after twelve months are given in this paper.

### 3.2 NCAT Test Track

The NCAT Test Track is a 1.7 mile closed-loop full-scale asphalt pavement test facility. The track consists of forty-six 200-ft test sections sponsored by a variety of agencies and corporations. Test Track research is conducted in three-year cycles consisting of forensics and reconstruction in the first year of a cycle followed by two years of nearly continuous traffic. Test sections are loaded by five tractor-triple-trailer vehicles circling the facility at 45 mph, 16 hours per day and 5 days per week. Approximately one-million laps are executed over each two-year traffic cycle. The research cycle for this study began in 2009 and will continue through the end of 2011. Track instrumentation includes load cells, strain gauges and temperature probes [2]. Strain measurements are correlated with temperature to determine strain/temperature profiles [3, 4, 5]. Falling weight deflectometer (FWD) measurements are conducted multiple times per month and the data analyzed with EVERCALC 5.0 to back-calculate material properties [2, 6]. Finally, calculated moduli are fit to an exponential temperature function [7, 8].

## 4 Rutting data of full depth SBS modified section N7

### 4.1 Test Sections N7/S9

As previously reported [9], Figure 1 shows the pavement cross sections with depths of embedded instrumentation for sections S9 (Control) and N7 (HiMA) while Table 1 contains the corresponding as-built material characteristics. The layers of each section were designed for optimum asphalt content using the same aggregate gradation between the control and the HiMA mixtures. The result, as shown in Table 1 was very similar design asphalt contents and in-place air voids between the two sections on a layer-by-layer basis. The aggregate gradations were held fixed between the HiMA and control mixtures and consisted of granite, limestone and sand.

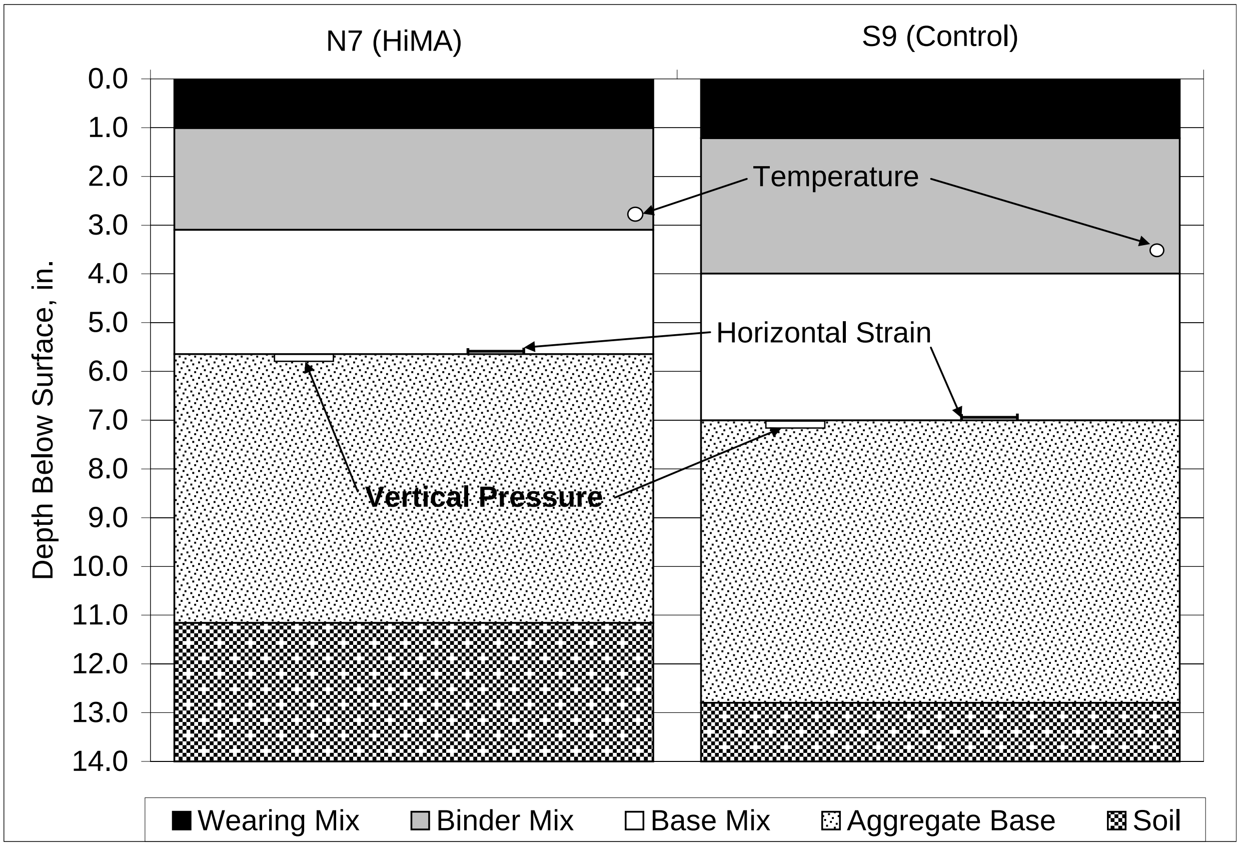


Figure 1: Experimental sections N7 and S9.

Table 1: Asphalt Concrete Layer Properties – As Built

| Layer | Wearing | | Binder | | Base | |
|---|---|---|---|---|---|---|
| Section | N7 | S9 | N7 | S9 | N7 | S9 |
| Thickness, in. | 1.0 | 1.2 | 2.1 | 2.8 | 2.5 | 3.0 |
| NMAS[a], mm | 9.5 | 9.5 | 19.0 | 19.0 | 19.0 | 19.0 |
| %SBS | 7.5 | 2.8 | 7.5 | 2.8 | 7.5 | 0.0 |
| PG Grade[b] | 88-22 | 76-22 | 88-22 | 76-22 | 88-22 | 67-22 |
| Asphalt, % | 6.3 | 6.1 | 4.6 | 4.4 | 4.6 | 4.7 |
| Air Voids, % | 6.3 | 6.9 | 7.3 | 7.2 | 7.2 | 7.4 |
| Plant Temp, $^{o}$F[c] | 345 | 335 | 345 | 335 | 340 | 325 |
| Comp. Temp, $^{o}$F[d] | 297 | 275 | 247 | 273 | 240 | 243 |

[a]Nominal Maximum Aggregate Size
**[b]Superpave Asphalt Performance Grade**
**[c]Asphalt plant mixing temperature**
**[d]Surface temperature at** which compaction began

The primary differences between S9 and N7 were the amount of polymer and overall HMA thickness. Section N7 contained 7.5% SBS polymer in each layer while S9 utilized more typical levels of polymer in the upper two layers with no polymer in the bottom layer. The nominal binder PG grade was PG 88-22. However, the formulation was designed to meet mixture toughness criteria as determined by beam fatigue and finite element modeling [10, 11] rather than a specific Superpave PG binder grade. The total HMA thickness in N7 was approximately 1.4 inches thinner than S9 to evaluate its ability to carry larger strain levels more efficiently.  Both sections were constructed on top of approximately 5.5 inches of dense-graded crushed granite aggregate base on top of the subgrade.

The mixing and compaction temperatures listed in Table 1 were arrived at through discussions with the polymer supplier, plant personnel and the research team.  Test mix was generated at the plant and test strips were paved to determine optimum compaction temperatures.  As shown in Table 1, the HiMA mixtures required higher mixing and compaction temperatures due to the increased polymer content.

**4.2 Rutting data comparison**

Rutting, or permanent deformation, is a primary distress in asphalt pavements. Rutting can occur either within the bound layers of a pavement or throughout the full depth of a pavement structure. There are two mechanisms of permanent deformation within a pavement layer, densification and shear strain. Densification is limited by the void structure of the pavement and is usually not severe. Shear strain, on the other hand, causes dilation and weakening of the pavement and thus can accelerate leading to failure. Finally, if too much load is transmitted through the pavement structure to the subgrade, the stress can cause deformation in the subgrade [12, 13] and the entire pavement structure. With expected higher subgrade stress due to the thinner structure, this was a concern for the design of Section N7.

To characterize the rutting susceptibility of the mixtures in this study, the surface and base mixtures were tested using loaded wheel testers and a repeated loading test. This data was previously reported [14].

*4.2.1 Asphalt Pavement Analyzer Testing*

The rutting susceptibility of the highly modified and control base and surface mixtures were evaluated using the Asphalt Pavement Analyzer (APA). Rutting susceptibility is most typically measured on surface mixtures, but for this experiment it was desirable to determine rutting potential for both the fine surface mix and coarse base mix. The base mix for the control section S9 was also tested. APA testing of the control section intermediate mix was not part of the original experimental design and there was not sufficient retain loose mix.

Testing was performed in accordance with AASHTO TP 63-09.  The samples were prepared to a height of 75 mm and an air void level of 7 ± 0.5 percent.  Six replicates were tested for each mix. The samples were tested at a temperature of 64$^{o}$C (the 98 percent reliability temperature for the high PG grade of the binder).   Typically, these samples are tested at the high binder PG grade.  However, for the Test Track, a constant testing temperature for all mixes was desired to facilitate relative comparisons between the mixes.   The samples were loaded by a steel wheel (loaded to 100 lbs) resting atop a pneumatic hose pressurized to 100 psi for 8,000 cycles. Manual depth readings were taken at two locations on each sample after 25 loading cycles and at the conclusion of testing to determine the sample rut depth (Table 2).

Table 2 APA Test Results [14]

| Mixture | Average Rut Depth, mm | StDev, mm | COV,% | Rate of Secondary Rutting, mm/1000 cycles |
|---|---|---|---|---|
| Control – Surface | 3.07 | 0.58 | 19 | 0.140 |
| Control – Base | 4.15 | 1.33 | 32 | 0.116 |
| HiMA – Surface | 0.62 | 0.32 | 52 | 0.0267 |
| HiMA – Base | 0.86 | 0.20 | 23 | 0.0280 |

The APA is typically used as a pass/fail test to ensure that mixtures have suitable rutting resistance. Past research at the Test Track has shown that if a mixture has an average APA rut depth less than 5.5 mm, it should be able to withstand the 10 million equivalent single axle loads (ESALs) of a Test Track cycle without accumulating more than 12.5 mm of field rutting [15]. Considering this threshold of 5.5 mm, a one-sample *t*-test ($\alpha = 0.05$) shows all four mixtures have average rut depths less than the given threshold. Thus, the mixtures are not expected to fail in terms of rutting on the 2009 Test Track.

The secondary rate of rutting in the APA was calculated by fitting a power function to the rut depth curves for two samples the left, right and center molds of the APA during testing as shown in Figure 2. These three average rates were then used to calculate a singular rate of rutting for each mixture. The primary rate of consolidation is taken as the initial slope of the rut depth curve and, for this work, the secondary rate is taken as the slope at the 8000$^{th}$ loading repetition. The results of this analysis are given in Table 2.

Of the four mixtures, the HiMA surface mixture had the best, or smallest, rate of rutting. This mixture also had the least amount of total rutting during the mix. The second most rut resistant mixture in terms of total rutting and rutting rate was the HiMA base mixture. This suggests that using the HiMA allows engineers to design both a flexible and rut resistant asphalt mixture.

One would normally expect that a coarser mix would be stiffer and thus more resistant to permanent deformation. The slightly better performance of the control surface mix versus the base is explained by the binder difference, PG 76-22 for the surface and PG 67-22 for the base. However, the HiMA pavement had the same binder in all courses so the APA performance of the surface versus the base is surprising.

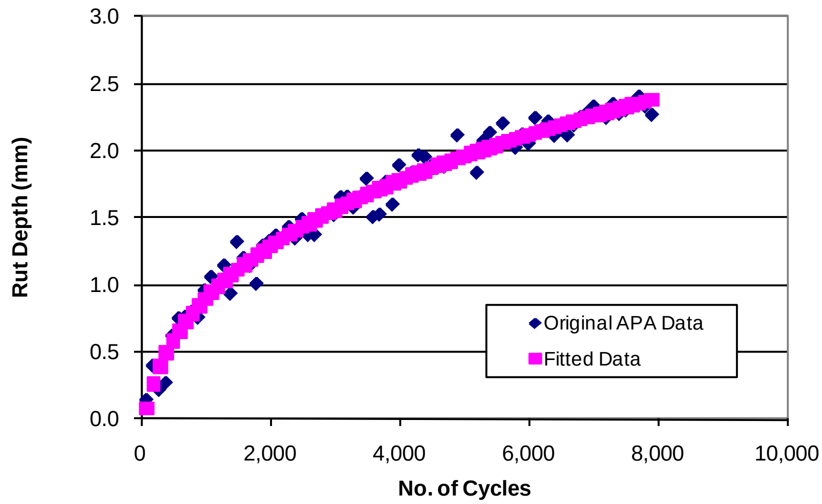


Figure 2: Example Rate of Rutting Plot for Two Samples in Center Mold [14]

### *4.2.2 Flow Number*

The determination of the $F_n$ for the mixtures was performed using the Accelerated Mixture Performance Test (AMPT). $F_n$ tests were conducted at a temperature of 59.5°C which is the LTPPBind 3.1 50% reliability temperature for the Test Track location at 20 mm from the surface of the pavement. The specimens were tested at a deviator stress of 87 psi without confinement. The tests were terminated when the samples reached 10 percent axial strain. For the determination of tertiary flow, the Francken model [15] was used (Equation 1). Non-linear regression analysis was used to fit both models to the test data was performed.

$$\varepsilon_p(N) = aN^b + c(e^{dN} - 1) \qquad \text{(Equation 1)}$$

where:

$\varepsilon_p(N)$ = permanent strain at 'N' cycles
N = number of cycles
a,b,c,d = regression coefficients

Figure 3 compares the average flow number values for the four mixes evaluated in this study. One sample of the HiMA surface mixture was considered an outlier and removed from the analysis as it never achieved tertiary flow. Even with this outlier removed, the HiMA surface mixture exhibited the largest flow number. The second best performing mixture was the HiMA base mixture. Its flow number of 944 was 5.76 times greater than that of the control base mixture.

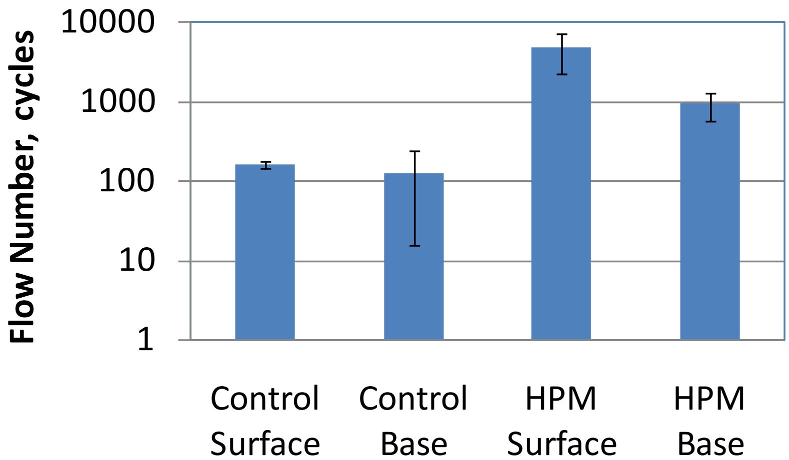


Figure 3: Flow Number Results (HPM = high polymer mix)

### *4.2.3 Rutting Test Comparison*

The APA and AMPT $F_n$ give quite similar rutting performance predictions. They give the same relative ranking as shown in Table 3. As shown in Figure 4, they also exhibit a strong log-log correlation with $R^2$ = 0.929.

Table 3: Rutting Test Comparisons [14]

| Mixture | APA Rut Depth, mm | $F_n$, cycles | APA Ranking | $F_n$ Ranking |
|---|---|---|---|---|
| Control – Surface | 3.07 | 164 | 3 | 3 |
| Control – Base | 4.15 | 129 | 4 | 4 |
| HiMA – Surface | 0.62 | 4825 | 1 | 1 |
| HiMA – Base | 0.86 | 944 | 2 | 2 |

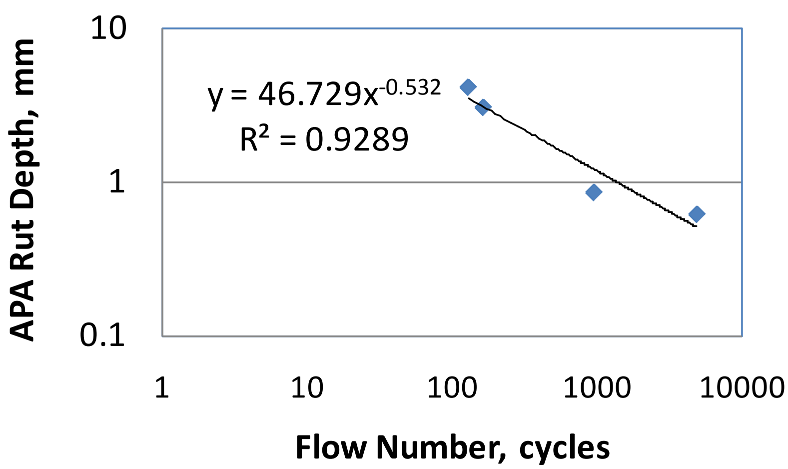


Figure 4: Rutting Test Comparisons. [14]

*4.2.4 Comparison with field data and modeling data*

Figure 5 shows the comparative measured rut depths of sections N7 and S9 as of August 2011. It shows a significant difference between the two pavements with the highly SBS modified pavement showing over 4X less rutting than the reference.

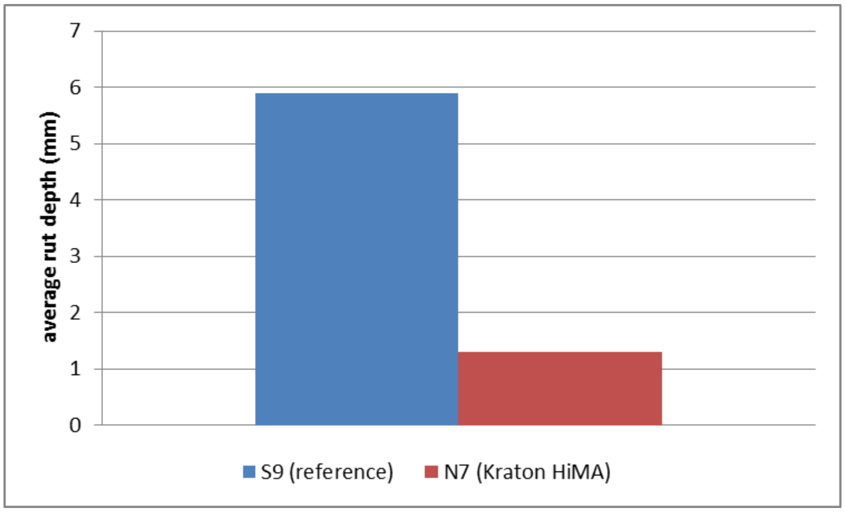


Figure 5: Measured rut depths on NCAT track

Delft University of Technology made a Finite Element Modeling of a similar high polymer modified pavement versus a control as part of their extensive research program on polymer modified base courses. Data from tension and compression tests was used as input for the Asphalt Concrete Response (ACRe) model. In the model the asphalt layer consisted of a base course asphalt mix paved on top of an unbound base as projected in figure 6 with dimensions as given in table 4. The mix designs were the same (23 mm NMAS), with an unmodified 40 pen asphalt for the control versus 7.5% SBS loading in the same asphalt for the highly modified mix. The thickness reduction in this experiment was 40%.

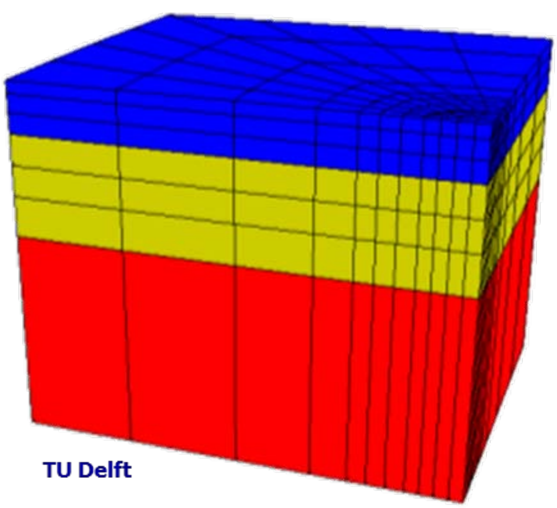


Figure 6: structure with asphalt layer (blue) on top of subbase (yellow) and subgrade (red)

Table 4: dimensions modeled structure

| layer | Thickness (m) | Young’s modulus (MPa) |
|---|---|---|
| Asphalt | 0.15<br>0.25 | Calculated in CAPA |
| Sub base | 0.3 | 300 |
| Sub grade | 15 | 100 |

The vertical deformations calculated using finite element modeling have been put together in figure 7 for a pavement structure of 250 mm unmodified asphalt mix and 150 mm of high polymer modified asphalt. The loading is a half sinusoidal pulse load of 25 ms duration with a stress amplitude of 0.8 MPa.

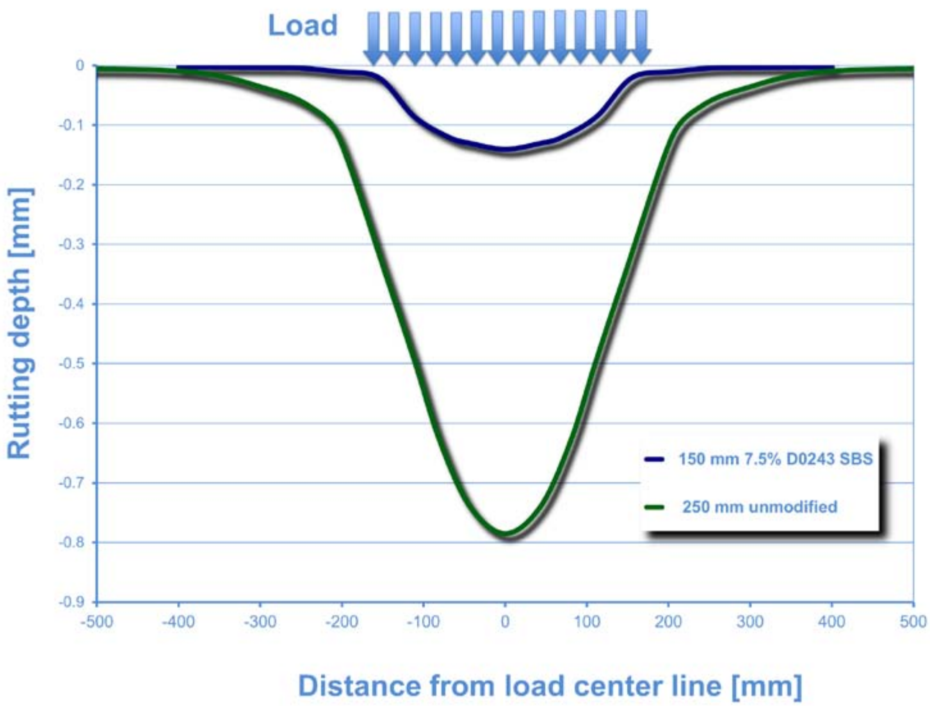


Figure 7: Rutting profile from finite element analysis after 9000 load repetitions for thin high polymer pavement and thicker standard pavement

The rutting depth of the reference structure is about 5 times higher than for the high polymer modified pavement. This is fully in line with the results from the APA where 8000 load repetitions were applied, very similar to the 9000 load cycles from the modeling work. On the test track the section has seen approximately 9.5 million load cycles to date. Advanced modeling, APA, AMPT $F_n$ and actual rut depths on the test track all give similar relative performance between the highly modified pavement and the control which provides a high level of confidence on the validity of the results.

## 5 Rehabilitation of a failed pavement with a highly SBS modified mix

Bottom up-cracking in flexible pavements often requires full depth removal and replacement of the cracked pavement. In many, perhaps most cases, full depth replacement is not economically practical and also causes unacceptably long road closures. Thus a surface or structural mill and overlay is the most common treatment for cracked asphalt pavement. This may result quickly in reflection cracks propagating to the surface as noted by Pais and Pereira [16]. Tsai et al. [17] cite reflection cracking as one of the main distresses in asphalt concrete (AC) overlays. Nevertheless, the motivating factors to do relatively shallow milling and overlay of a distressed area typically outweigh the performance challenges leading to frequent repairs and user delay.

A common approach to improve cracking resistance is through polymer modified asphalt (PMA) mixtures. Von Quintus et al. [18] noted the routine use of PMA mixtures for flexible pavement structures and overlays and found a 5 to 10 year extended service life for deep strength AC pavements. It should be noted that this study had mixtures containing in the range of 2 – 3% polymer. This is in line with common practice in the USA.

As previously reported [19], the section studied in this investigation, N8, was originally constructed in 2006 as part of a perpetual pavement design experiment sponsored by Oklahoma Department of Transportation (ODOT) [2, 20, 21]. Figure 8 illustrates the cross-sections of N8, starting with the new construction in 2006, the mill-and-inlay with paving fabrics at the beginning of the 2009 experiment and the mill-and-inlay with HiMA (Highly Modified Asphalt) in August 2010. These rehabilitations are discussed in detail below.

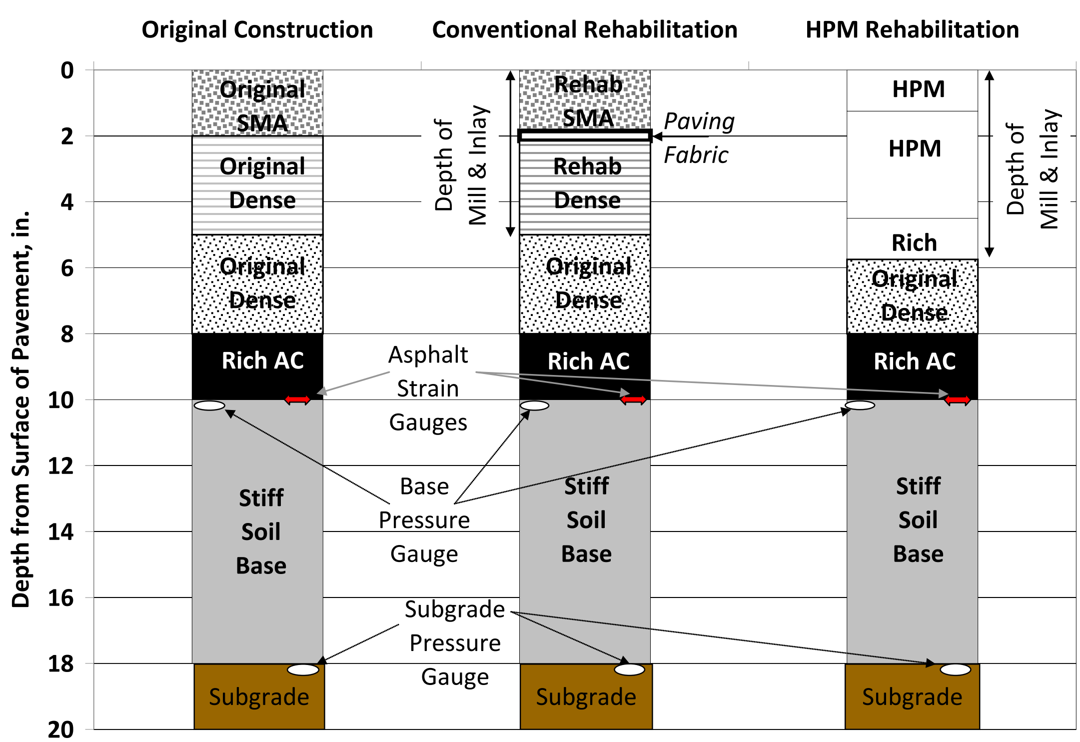


Figure 8: Section N8: original construction and rehabilitation cross sections. [19]

### 5.1 Original Construction

Section N8 was the thinner of two test sections (the thicker, 14 inch section is still performing well) sponsored by the ODOT in the 2006 research cycle to study the perpetual pavement thickness design concept. The original subgrade under the test track was fairly stiff. In an attempt to take into account the softer subgrade materials in Oklahoma, the soil under the sections was excavated to a depth of 4 feet and replaced with soft subgrade. The top 8 inches of the soft subgrade were again replaced with the excavated, stiffer material to simulate lime stabilization.

The total asphalt thickness of section N8 was 10 inches, consisting of a 2-inch rich bottom layer, 6 inches of dense Superpave mix, and a 2-inch stone matrix asphalt (SMA) surface. Information on the design, production, and placement of all the layers in both sections has been previously documented [2, 8, 21]. Roughness began to increase in section N8 near the end of the 2006 research cycle after approximately 7 million ESALs. The first cracks occurred at the surface after 8.3 million ESALs, and the section was in need of rehabilitation by the end of the 2006 cycle (i.e., 10 million ESALs).

### 5.2 2009 Mill and Inlay with Paving Fabric

The first rehabilitation of section N8 consisted of a conventional mill and inlay of 5 inches. This is the standard practice of ODOT for these types of structural failures. The 5 inches were subdivided in 3 inches of dense Superpave mix under 2 inches of SMA (see figure 8). The mixes were the same as the original pavement. Geotextile fabrics were used to determine if they would affect the propagation of reflective cracking.

It took longer before cracks started to form in the areas where the geotextile interlayers had been used. However, after cracking was observed, the pavement deteriorated faster in the areas with the interlayers. Figure 9 shows the state of the pavement in the most distressed area which was close to where a paving fabric was installed. The visible cracks are mainly surface shearing cracks, but forensics revealed that cracking extended down into the pavement and rutting extended to the subgrade. After 3.5 million ESALs the structure had completely failed. At this point trucks could not drive over this section anymore and rehabilitation was needed again to be able to continue trucking. This posed a challenge for track operations. A rehabilitation solution was needed that could be executed in a timely manner and that would last through the remainder of the trafficking cycle.

Figure 9: N8 Pavement failure after conventional mill and inlay at 4 million ESALs. [19]

**5.3 2010 – Mill and Inlay with Highly Modified Asphalt**

The good performance of the adjacent N7 full depth asphalt section with high polymer content prompted NCAT to propose a similar structure for the N8 rehabilitation. The details of the N7 structure can be found in paragraph 3.3 of this paper. The original proposal was to duplicate the N7 with a 19 mm base and binder course and 9.5 mm surface. This would provide maximum stiffness and thus minimize the potential for further subgrade rutting. ODOT countered with a proposal to change the bottom lift to a richer 9.5 mm mix, the same as the surface course, to better mitigate reflective cracking from the remaining cracked bound pavement. In the end, the decision was to go with the rich, finer mix for the bottom lift with the same thickness as the wearing course. The thickness of the intermediate layer was increased to 3.25 inches to accommodate the change in the lower layer.

In total 5.75 inches were milled from the distressed pavement of N8 to accommodate the highly modified inlay in three layers. Prior to paving the inlay, a crack map was made on the milled pavement surface. These are visible in figure 10. Figure 10 also shows locations of FWD testing. This is however not included in this paper.

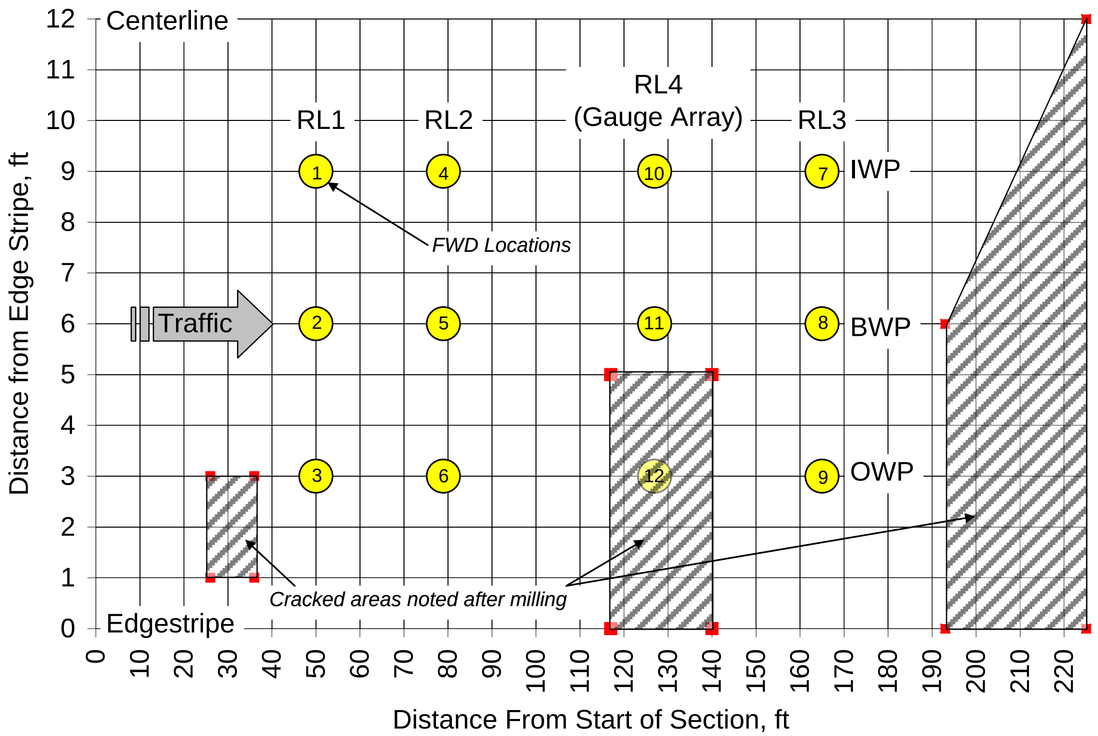


Figure 10: Cracked areas on milled surface with FWD locations. [19]

For this second rehabilitation no geotextile interlayers were used. As in the construction of section N7, the placement of the HiMA mix went without any problems. Now, after 4.8 million ESALs, the surface of the section exhibits only minimal rutting (1.2 mm) and no cracking. The visual state of the section as of June 2011 is shown in Figure 11 at a similar traffic loading of the original rehabilitation in Figure 9. Given the design choice that was made, the minimal rutting is particularly gratifying. Trafficking and monitoring of the renewed section N8 will continue through the 2012 track cycle.

Figure 11: Current state of section N8 with highly modified surface after 4.2 million ESALs.

## 6. Conclusions

The results on both the full depth high polymer pavement section (N7) and the high polymer overlay section (N8) at NCAT show continued good results. The loading cycle of N7 has been going on for two years now. The resistance to rutting has proven to be particularly good and the section is performing well in line with the expectations based on the APA testing, AMPT testing and finite element modeling. In all four evaluations the rutting depth of the reference structures are 4-5 times higher than for the high polymer structures.

As a result of the good performance of section N7, the opportunity arose to pave another section at NCAT in summer 2010. An adjacent section needed urgent repair as high deformations in the subgrade lead to severe rutting and cracking of the asphalt. A highly modified structural overlay mix was paved using mill and inlay.

Already after 12 months (4.8 million ESALs) a significant difference in visual status of the section can be noted compared to the previous, conventional structural overlay. While the latter showed severe cracking and rutting after 4.0 million ESALs, the high polymer overlay shows minimal rutting and no cracking at 4.8 million ESALs. This section will continue to be monitored through the 2012 track cycle.

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