PAVEMENT REHABILITATION USING HIGH POLYMER ASPHALT MIX

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ABSTRACT

Reflection cracking is a common occurrence when distressed asphalt concrete pavements are rehabilitated with a mill-and-inlay approach. Economic pressures often lead agencies to use this approach which facilitates the need for fatigue cracking resistant materials that can withstand a high strain environment and restore the structural integrity of the pavement. A newly formulated high polymer content asphalt mixture (HPM) was recently placed at the National Center for Asphalt Technology Pavement Test Track in a heavily distressed pavement section. In preparation for the inlay, approximately half the depth of the existing structure was milled and cracking was observed on portions of the milled surface. The inlay has performed extremely well with respect to rutting, cracking and ride quality. The focus of this investigation, however, was to examine the structural response of the section before and after the HPM inlay. Extensive deflection testing and back-calculation quantified a statistically significant increase in the asphalt modulus of 55% after the inlay. There was also a noted reduction in the modulus variability. As expected from the increase in asphalt modulus, measured asphalt strain, aggregate base pressure and subgrade pressure were all reduced after the inlay at a reference temperature of 20°C. A 29% reduction in asphalt strain, a 51% reduction in aggregate base pressure and a 21% reduction in subgrade pressure were all found to be statistically significant. Given these findings, the HPM material was found to have an immediate and significant impact on the measured pavement properties and responses critical to its performance.

Keywords: SBS, modified bitumen, accelerated testing, pavement design, performance testing

INTRODUCTION

Complete structural restoration of a flexible pavement experiencing bottom-up fatigue cracking often requires full-depth removal and replacement of the cracked pavement. As noted by Pais and Pereira (*1*) simply overlaying a cracked pavement may quickly result in reflection cracks propagating to the pavement surface. Tsai et al. (*2*) cite reflection cracking as one of the main distresses in asphalt overlays. Despite this problem, there are strong motivating factors for conducting relatively shallow milling of the distressed pavement followed by overlay. These factors are largely economic as full-depth reconstruction costs, in addition to imposed user delay, can override the need to achieve fully restored structural integrity. The result is often just a few years of adequate performance at which time cracking again appears (*1*).

To address the need for materials that can withstand the high stresses and strains encountered in an overlay, or mill-and-inlay pavement rehabilitation, there have been many efforts to design crack-resistant bituminous materials. For example, a Russian study (*2*) cited using synthetic resin and granulated synthetic rubber to modify bituminous mixtures and achieve higher cracking resistance. Some field studies of these materials in Russia have confirmed their reduction in reflection cracking (*3*). Another study reported significant increases in fatigue cracking resistance of rubber-modified asphalt over traditionally dense-graded asphalt (*4*). Using AASHTO TP 8-94 to conduct bending beam fatigue tests, Sousa, et al., (*4*) found the fatigue life of the rubber-modified asphalt to be ten times greater than that of dense-graded asphalt at strain levels ranging from 100 to 1000 $\mu\varepsilon$.

Another approach to improve cracking resistance is through polymer-modified bitumen (PMB) mixtures. Von Quintus et al. (*5*) noted the routine use of PMB mixtures for flexible pavement structures and overlays and found a 5 to 10 year extended service life for deep strength asphalt pavements. It should be noted that this study, as is the general practice when modifying bitumen with polymer, had mixtures in the range of 2-3% polymer.

Recently, Kraton Performance Polymers, Inc. has developed a low viscosity PMB formulation with 7-8% polymer. As previously cited (*6*), this high-polymer mix (HPM) has practical compatibility and viscosity for drum plant or pug mill production as well as for laydown and compaction. At this content, the polymer forms a continuous network in the asphalt turning it into an elastomer with substantially increased resistance to permanent deformation and fatigue cracking. Four point bending beam fatigue testing on mixtures with these binders has shown well over an order of magnitude increase in fatigue life (*7-9*). In addition, 3D finite element modeling using the continuum damage Asphalt Concrete Response (ACRe) model developed by TU Delft *(10,11)* predicts improved resistance to permanent deformation and fatigue damage even with a 40% reduction in thickness (*12-14*).

The first field-trial of this HPM was placed in 2009 at the National Center for Asphalt Technology (NCAT) Pavement Test Track. The purpose of the trial was to construct a new section made entirely of the HPM, but with reduced thickness relative to a control section, to evaluate its use for new construction. As previously reported (*6*), the section was performing better than the control section after approximately 4.1 million equivalent single axle loads.

During the testing of the HPM section, another unrelated section was experiencing severe cracking distress. The structure in need of rehabilitation consisted of 250 mm of asphalt, over a stiff soil base layer, on a soft clay subgrade that had failed near the end of the previous research cycle (*15*). An earlier rehabilitation attempt using conventional mix with a fabric interlayer had failed relatively quickly. Forensics on the failed structure revealed full depth distresses extending down to the subgrade. Since the nearby HPM section had performed well in a new construction scenario, it was proposed to attempt a mill-and-inlay with the HPM material. The sponsor of this section, the Oklahoma Department of Transportation (ODOT), endorsed using the HPM design for the second rehabilitation, but elected to reduce the size of stone in the base course, in effect duplicating the wearing course in composition and thickness. To optimize the cracking resistance of the lower layer, it was produced with lower air voids as a rich bottom. No fabric interlayers were used in the second rehabilitation.

1. OBJECTIVE AND SCOPE OF WORK

The objective of this paper was to document the HPM as an inlay material at the NCAT Test Track on a heavily cracked pavement. This information will be key to its adoption as an overlay/inlay material on the public roadway network. This paper describes the performance and rehabilitation history of section N8, including the two rehabilitation cycles using paving fabric and the HPM inlay. Extensive deflection testing using a falling weight deflectometer (FWD) facilitated an analysis of back-calculated layer moduli. Additionally, embedded pavement instrumentation enabled a detailed structural characterization of the section.

2. FACILITY AND TEST SECTION

The NCAT Pavement Test Track is a 2.7 km closed-loop full-scale flexible pavement test facility located in Opelika, AL. Sixty-six meter test sections are loaded with approximately ten-million equivalent single axle loads (ESALs) over a two-year test cycle. During this time, pavement response, deflection and performance measurements are made on a routine basis. Precise climate records and traffic data, applied by a fleet of tractor triple-trailers, are also kept during the test cycle. The section studied in this investigation, N8, was originally constructed in 2006 as part of a perpetual pavement experiment sponsored by ODOT (*15-17*). Figure 1 illustrates the cross-sectional history with new construction in 2006, the mill-and-inlay with paving fabrics at the beginning of the 2009 experiment and the mill-and-inlay with HPM in August 2010. The depths of gauges are also shown in Figure 1. Further details regarding these cross-sections are provided below.

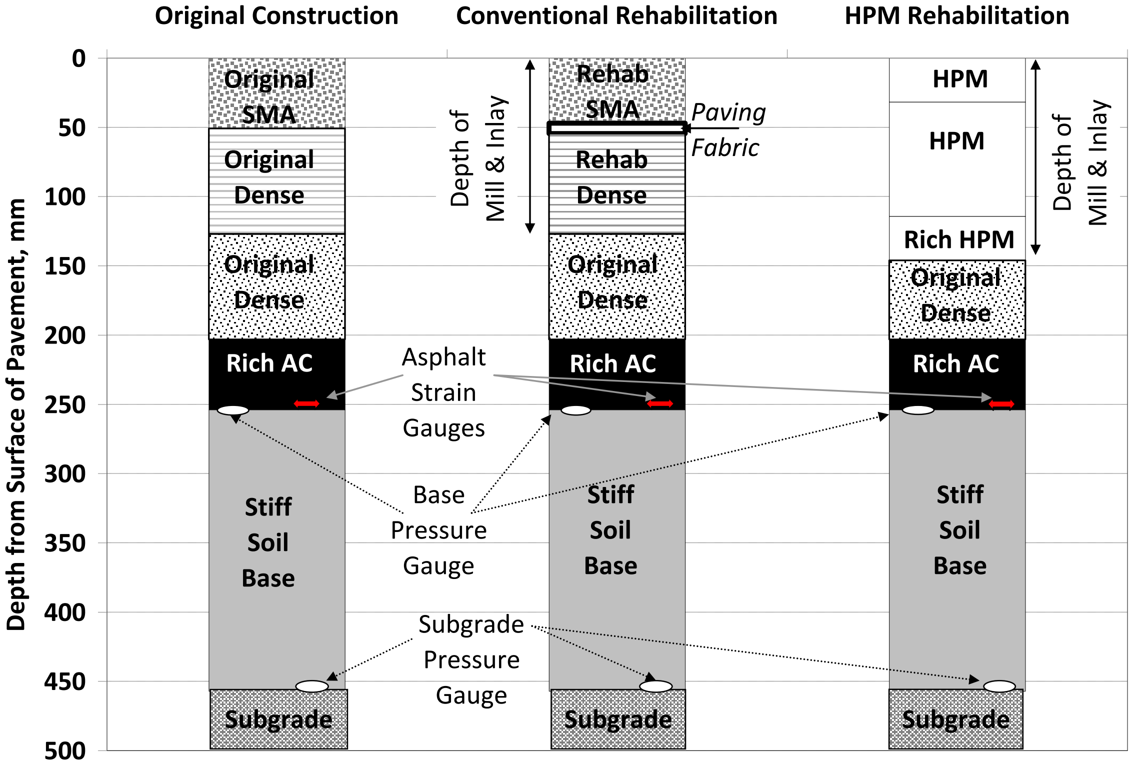

FIGURE 1 : Section N8: original construction and rehabilitation cross sections.

3. PERFORMANCE AND REHABILITATION OF N8

The performance history was divided into three main parts, coinciding with the three cross-sections shown in Figure 1. Each of the subsections below provides further details of each phase in terms of performance and rehabilitation.

4.1 Phase I – Original Construction

Section N8 was the thinner of two test sections sponsored by ODOT in the 2006 research cycle to study the perpetual pavement thickness design concept. The original stiff Test Track subgrade under these two sections was excavated to a depth of 1.2 m and replaced with a soft subgrade that was more representative of roadway soils in Oklahoma. The top 200 mm of the imported soft subgrade was replaced with the same stiff material that had been removed to simulate lime stabilization. As seen in Figure 1, section N8 had a total asphalt thickness of 250 mm, consisting of a 50 mm rich bottom layer, 150 mm of dense Superpave mix, and a 50 mm stone matrix asphalt (SMA) surface. The rich-bottom layer was a mixture designed to 2% air voids rather than 4% in the other Superpave layers (thus, a higher binder content). Information on the design, production, and placement of all the layers in both sections has been previously documented (*16-18*). Roughness began to increase in section N8 near the end of the 2006 research cycle after approximately 7 million ESALs. Cracking first reached 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).

4.2 Phase II – Mill and Inlay with Paving Fabric

As seen in Figure 1, the initial rehabilitation of the failed section consisted of a conventional 125 mm mill and inlay, which is ODOT's standard practice for the type of structural failure observed. The 125 mm inlay consisted of 75 mm of dense Superpave mix under 50 mm of SMA. The mixes used for this inlay were identical to the original mixes placed in the structure. At the request of ODOT researchers, geotextile fabric interlayers were used in two different areas of the inlay to determine if they would affect the onset of reflective distresses.

Although cracks took longer to form in the areas of the mat where the fabric interlayers were placed, pavement condition in both of the areas in which fabric interlayers were installed deteriorated more rapidly after cracking was observed. Figure 2 illustrates the failed pavement surface in the most severely distressed area which was in close proximity to the installed paving fabric. The cracks in this picture are primarily surface shearing cracks, though cracking did extend down into the pavement structure as confirmed forensically. The rehabilitated structure was completely failed after approximately 3.5 million ESALs at which point further mill-and-inlay options were considered.

FIGURE 2 : N8 Pavement failure after conventional mill and inlay.

4.3 Phase III – Mill and Inlay with HPM

A nearby, newly constructed and unrelated, HPM section that had exhibited good performance (N7) consisted of three lifts of HMA blended with binder modified with Kraton's D 0243 styrene-butadiene-styrene (SBS) polymers. The 57 mm base lift and 57 mm intermediate lift each contained 7.5 percent polymer and 19 mm stone, while the 32 mm thick wearing course was designed with a 9.5 mm NMAS aggregate blend. ODOT officials endorsed using the HPM design but elected to change the size of stone in the base course to 19 mm, in effect duplicating the wearing course composition and thickness. To optimize the cracking resistance of the smaller NMAS lower layer, it was produced with lower air voids for a rich bottom approach. The thickness of the intermediate layer was increased to 83 mm to accommodate the change in the lower layer.

The distressed pavement was milled to 145 mm to accommodate the HPM inlay. Before paving, however, a crack map was developed on the milled pavement surface. Figure 3 shows the areas of observed cracking. The numbered circles in the figure are locations of FWD testing which will be discussed further below. FWD tests were conducted at each of the four random locations (RL1, RL2, RL3 and RL4) and corresponding wheel path offsets (inside wheel path (IWP), between wheel path (BWP) and outside wheel path (OWP)). It should be noted that the instrumentation array was centered in the outside wheel path at RL4. The shaded area of cracking contains the area in which the gauges were installed. As will be discussed below, this meant that strain and pressure measurements were made at the bottom of the remaining cracked asphalt with the HPM on top.

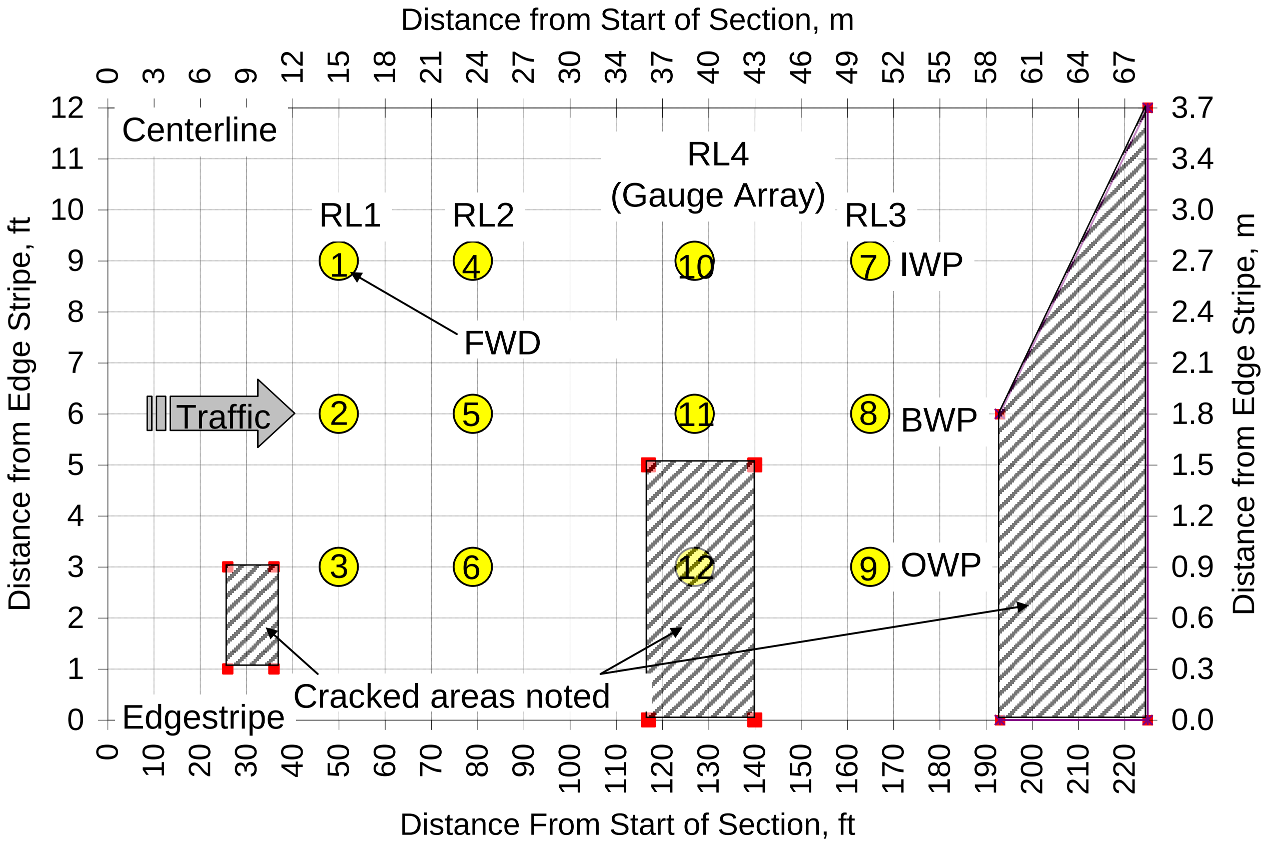

FIGURE 3 : Cracked areas on milled surface with FWD locations.

Fabric interlayers were not used in the second rehabilitation. No unusual problems were encountered in the production or placement of the inlaid HPM mix. After almost 5 million ESALs on the new HPM surface (1½ million ESALs more than the conventional rehabilitation), no changes in surface condition have been noted. The remainder of this paper is focused on examining pavement responses related to the performance of the HPM inlay.

4. STRUCTURAL PAVEMENT RESPONSES

As noted above, section N8 was originally constructed in 2006 as part of a structural evaluation of perpetual pavement concepts. An important and unique component of this study was the embedded instrumentation to measure tensile strain at the bottom of the asphalt and vertical compressive stresses in the top of the base and subgrade layers, respectively. The gauges and installation have been previously documented (*15-17*). Measurements from these instruments were used, as noted below, to determine pavement response before and after the HPM mill-and-inlay. Furthermore, extensive deflection testing using a Dynatest Model 8000 FWD from which back-calculated asphalt moduli were determined were critical to this analysis. The following subsections detail these analyses.

5.1 Back-calculated Asphalt Moduli

At the beginning of the 2009 experiment, FWD testing was conducted approximately every other Monday on section N8. As noted in Figure 3, three lateral offsets (between wheel path (B), inside wheel path (I) and outside wheel path (O)) at four random locations within 15 m sub-sections were subjected to deflection testing. At a given location on a given test date, each location was subjected to four drop heights and three replicates at each height. Only the data from the 4,100 kg drop height are presented here. Back-calculation was conducted using EVERCALC 5.0 which had been previously used effectively with Test Track deflection data (*18-19*).

Figure 4 shows the modulus versus mid-depth pavement temperature trends for N8 before and after the HPM mill-and-inlay. The data represent all locations within the section and the data were filtered such that only results from back-calculation with less than 3% root mean square error are shown. The best-fit exponential regression trendlines show a clear distinction between the two data sets. It is interesting to note that the lines are nearly parallel indicating little change in the influence of temperature, but the modulus appears to have increased by approximately 55% after the HPM mill-and-inlay.

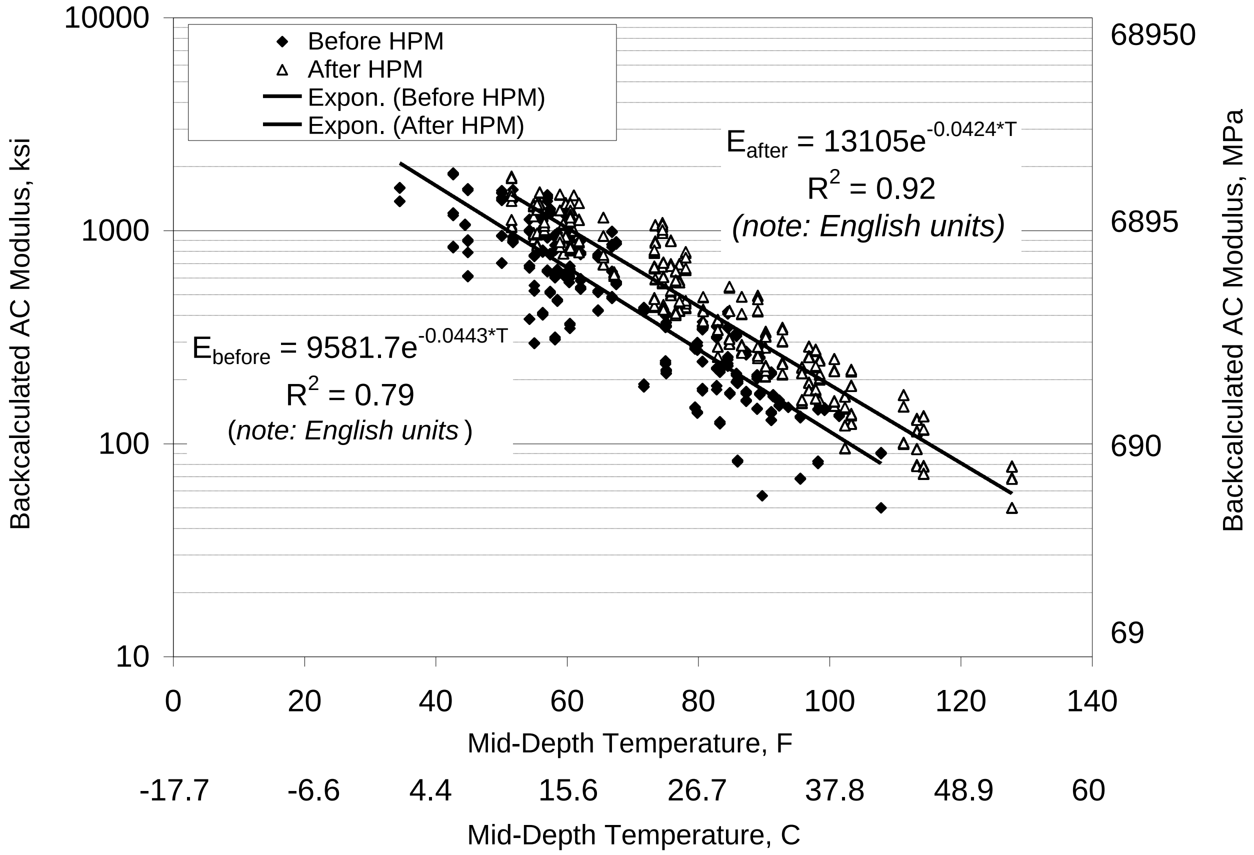

FIGURE 4 : Back-calculated asphalt moduli before and after HPM mill-and-inlay

Further comparisons between data sets were conducted with temperature-normalized asphalt moduli at 20 °C. Using the regression coefficients in Figure 4, for each condition (before and after), the asphalt moduli were brought to the standard temperature by:

$$E_{T_{ref}} = E_T * e^{k_2*(T_{ref}-T)} \quad \text{(Equation 1)}$$

where:
E_{Tref} = back-calculated asphalt modulus at reference temperature, ksi (MPa)
E_T = back-calculated asphalt modulus at the temperature during testing, ksi (MPa)
k_2 = condition-specific exponential regression coefficient from Figure 4
T_{ref} = reference temperature, 20 °C
T = temperature during FWD test, °C

Figure 5 shows back-calculated asphalt modulus at 20 °C versus test date. Differences before and after the HPM are clearly visible. Both the modulus magnitude and variability appear to change dramatically after the HPM. The coefficient of variation (standard deviation / mean) in the "before HPM" condition was 47% while it was reduced to 26% in the "after HPM" condition. Highly variable and relatively low moduli would be expected for a deteriorating pavement. The HPM appears to not only increase the modulus of the section, but also make it more homogeneous throughout with less overall variability on any given date of testing.

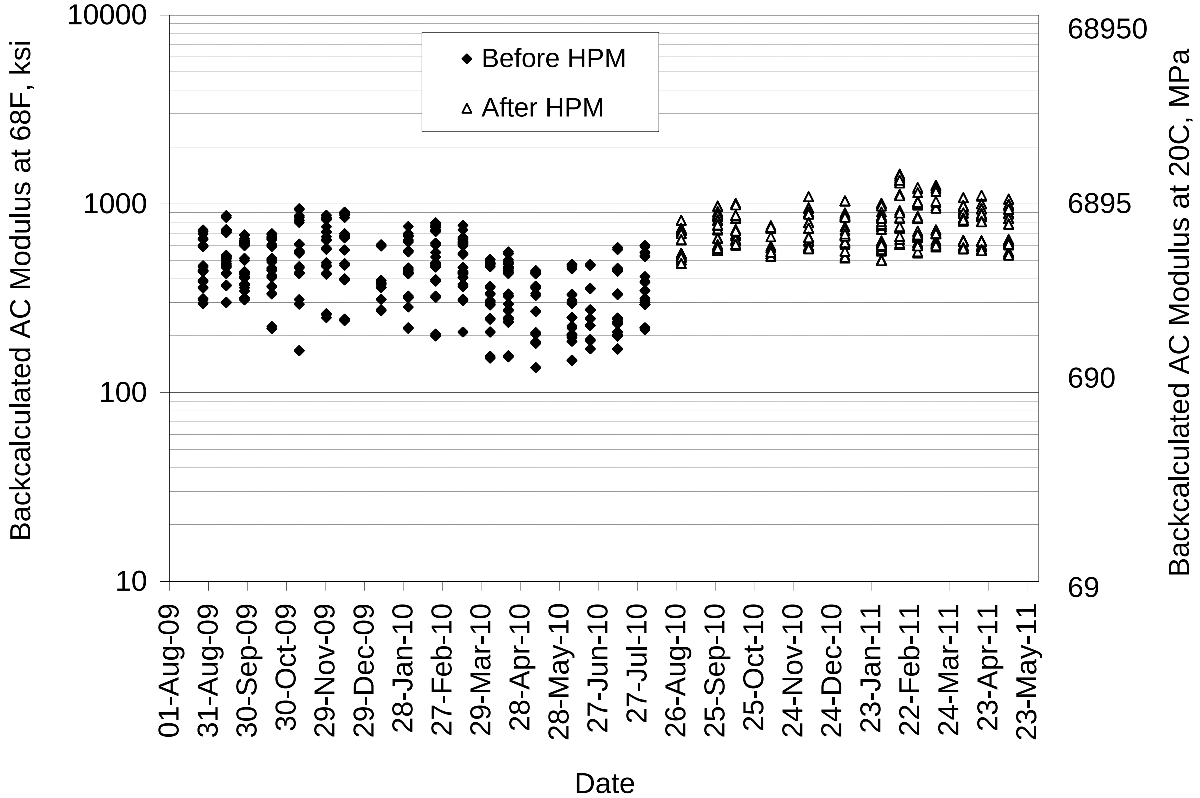

FIGURE 5 : Back-calculated asphalt moduli before and after HPM mill-and-inlay

Figure 6 shows the average and standard deviation of back-calculated asphalt moduli, at 20 °C, at each of the 12 test locations within N8. These data represent all the test dates presented in Figure 5. Also included in Figure 6 are the ratios of moduli after the HPM to before HPM at each location. Two-tailed statistical t-testing of the paired moduli data indicate statistically different average values in all cases (p-value < 0.0000). The "After/Before" series in Figure 6 shows the range of increase in modulus to vary from a factor of 1.38 to 2.76. The significance of these increases, in the context of pavement response, is explored in the following subsection.

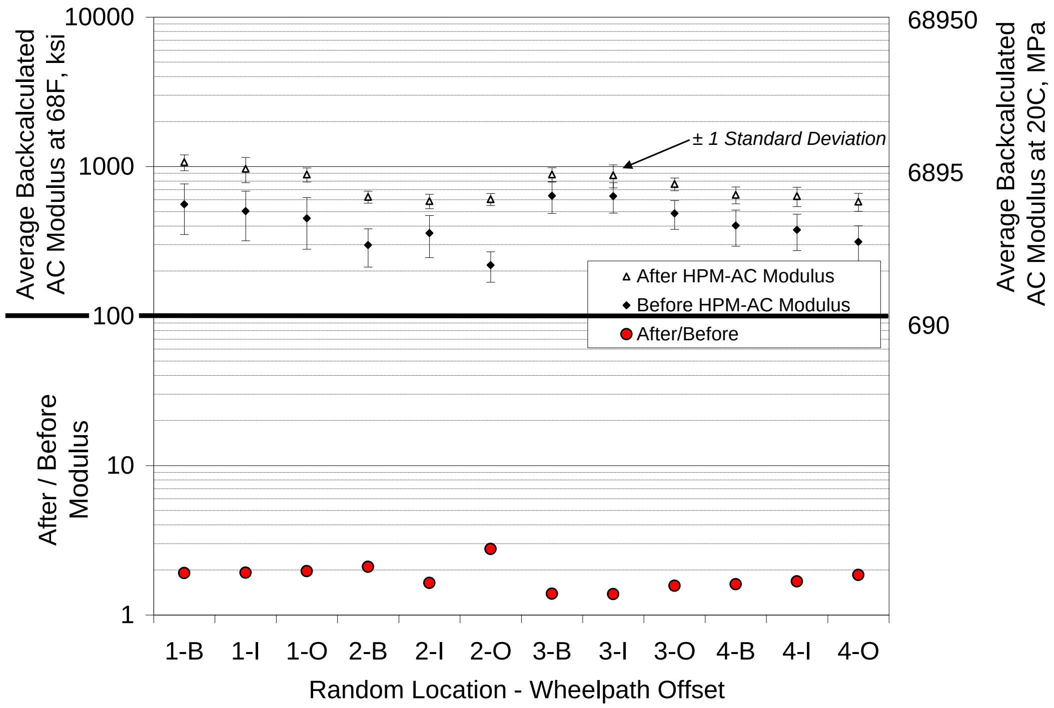

FIGURE 6 : Location-specific moduli and ratios before and after HPM.

5.2 Measured Pavement Responses

Three sets of measurements were obtained during this investigation. Tensile strain at the bottom of the asphalt served as an indicator of cracking performance. Vertical pressures in the aggregate base and subgrade are often considered in the context of rutting. For the purposes of this investigation, as done with the back-calculated asphalt modulus, comparisons were made before and after the HPM mill-and-inlay.

Measurements were made on a weekly basis. A data collection cycle, on a given date, consisted of collecting fifteen truck passes from which the "best hit" was determined for each of the three axle types (steer, tandem and single). The data presented here represent only the single axles since they caused the highest pavement responses and the other axle types exhibited similar trends.

Before significant distresses were noted in N8 during the 2009 research cycle, a strain-temperature relationship was developed to compare newly-collected strain measurements with what had been determined during the 2006 research cycle. Figure 7 compares these two data sets and indicates that even with the mill-and-inlay at the start of the 2009 experiment, there was a general increase in strain level. In other words, the original mill-and-inlay did not apparently improve the structural cross section with respect to strain response.

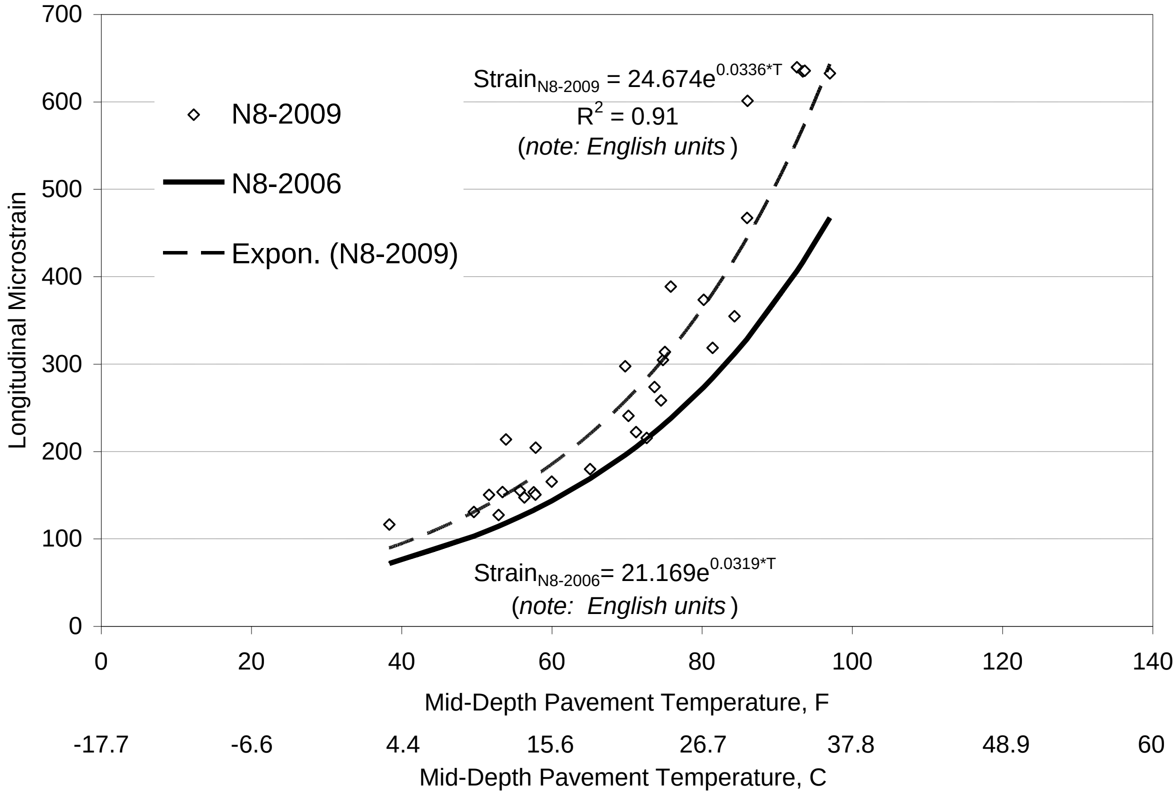

FIGURE 7 : Strain-temperature relationship from Phase I (2006) and Phase II (2009) through May 2010

Figure 8 compares the strain-temperature data between the before and after HPM conditions. It is interesting to note the general reduction in strain level with an increase in strain variability indicated by the lower R^2 in the "after HPM" condition. Recall that approximately half the asphalt depth was removed and replaced with HPM. As shown in Figure 3, cracking was observed at the top of the milled surface, prior to inlay, indicating cracking below. Therefore, it is reasonable to expect a decrease in strain though it may be more variable since the layer in which the strain gauges are embedded was cracked.

Figure 9 shows a similar trend for the aggregate base pressure as observed with the asphalt strain. Namely, reduction in response and a corresponding increase in variability. Curiously, Figure 10 shows reduction in response with *lower* variability for subgrade pressure after the HPM mill-and-inlay. Though a full theoretical explanation for this behavior is beyond the scope of this paper, it could be related to the subgrade pressure plate's proximity to the distressed asphalt. The subgrade plate had the aggregate base layer separating it from the asphalt, while the other two gauges (strain and base pressure) were right at the asphalt/aggregate base interface. Therefore, it is reasonable to expect a lower impact on measured response for this more deeply-buried gauge.

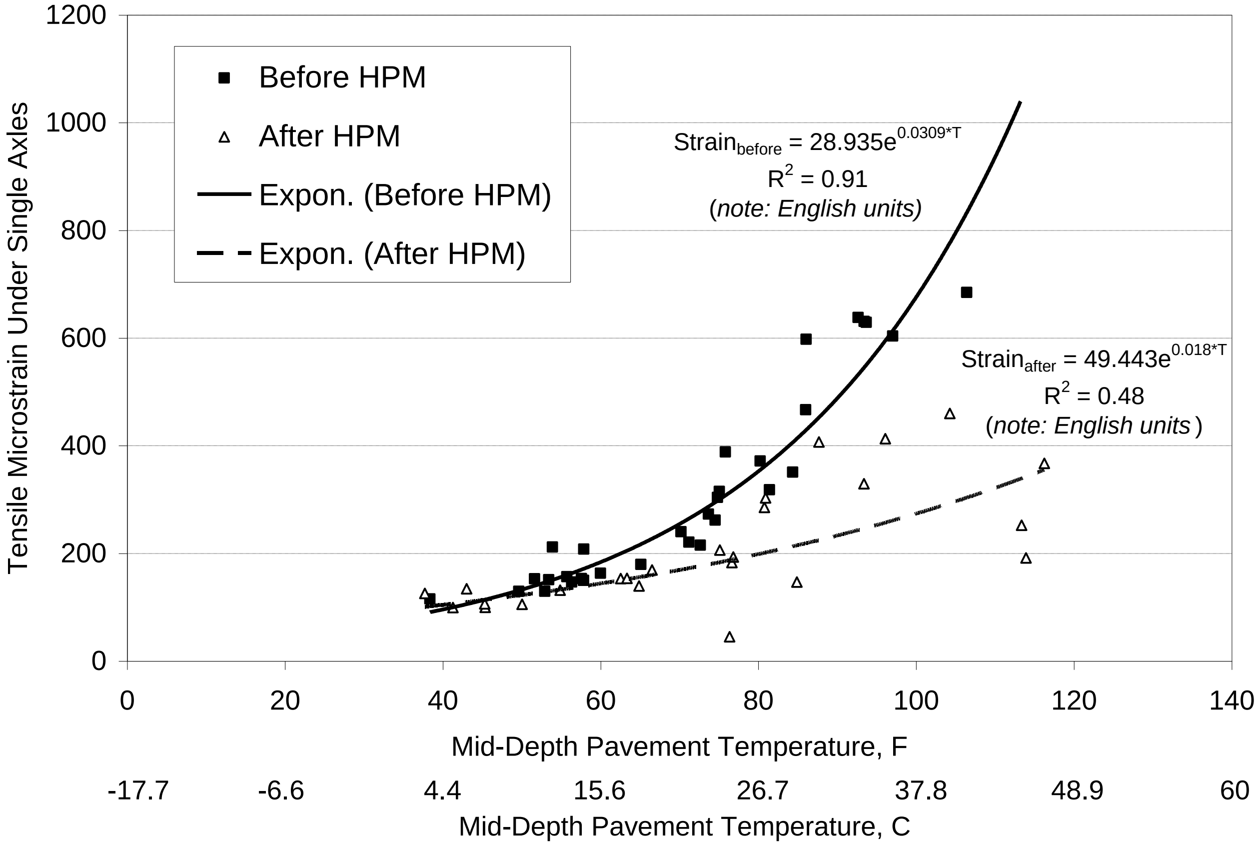

FIGURE 8 : Strain before and after HPM mill-and-inlay

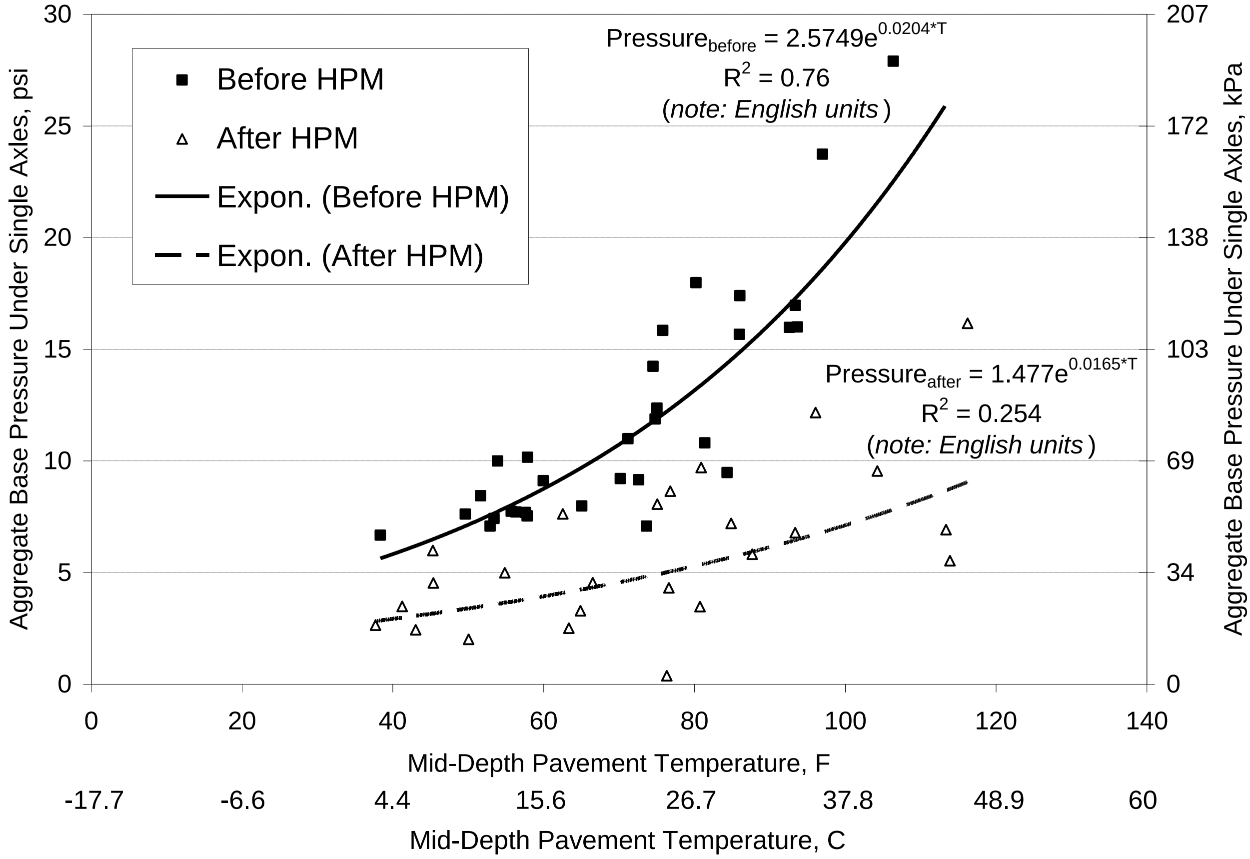

FIGURE 9 : Base pressure before and after HPM mill-and-inlay

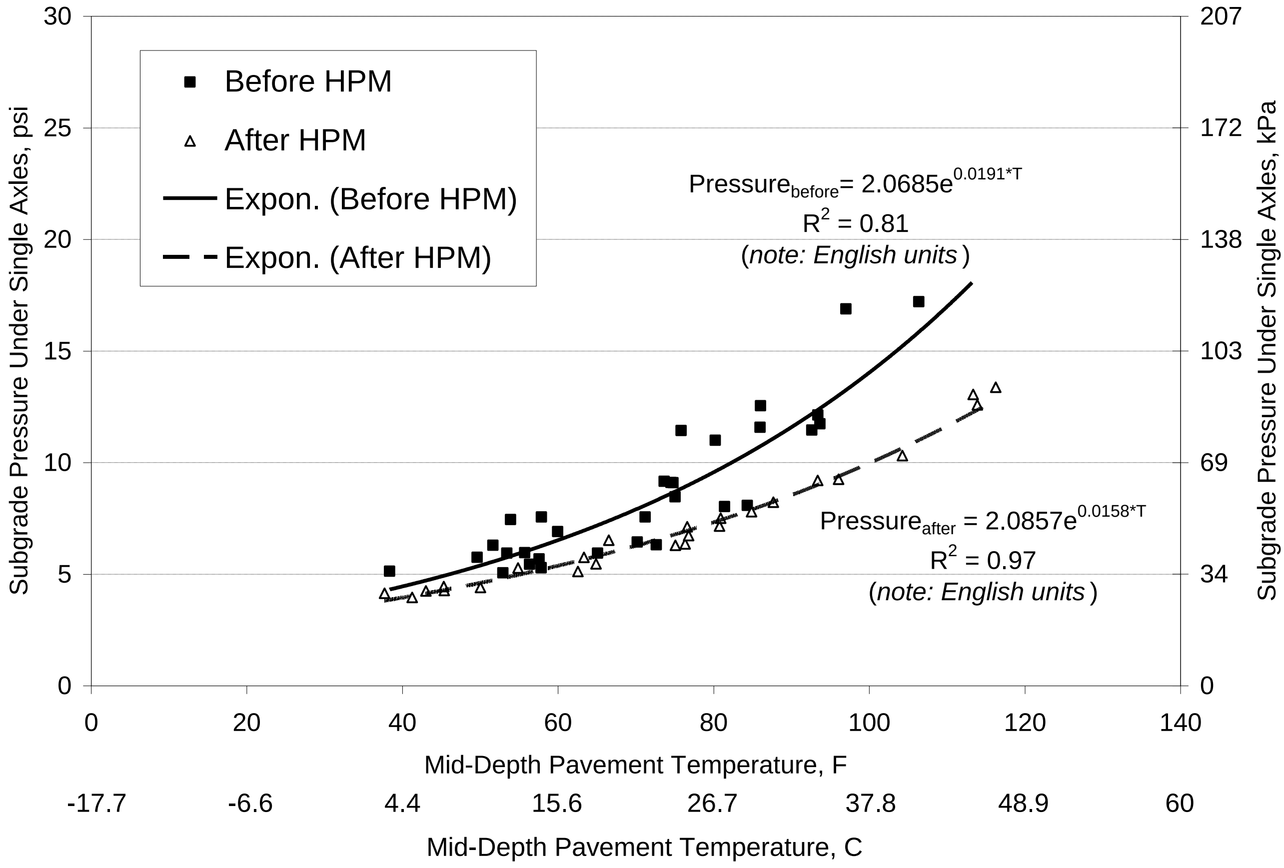

FIGURE 10 : Subgrade pressure before and after HPM mill-and-inlay

Following the format of equation 1, pavement responses were normalized to a 20 °C reference temperature. The exponential coefficients from Figures 8, 9 and 10 were used to generate average responses and corresponding standard deviations. Figure 11 summarizes the data. In the figure, all paired "Before" and "After" responses were found to be statistically significant using a two-tailed t-test ($\alpha = 0.05$). In all cases, there was a net reduction in pavement response resulting from the HPM. Strain was reduced 29%, base pressure 51% (with notable increases in variability) and subgrade pressure was reduced by 21%. Clearly, the increases in asphalt modulus noted above had a direct impact on the measured pavement response. This in turn, leads to better performance of the inlay than that previously experienced.

Another observation from Figure 11 was that the base pressure was lower than the subgrade pressure in the "after" condition. This was unexpected but could be explained by the cracking in the vicinity of the gauges and that the base pressure and subgrade pressure gauges were separated by 3.6 m, longitudinally. Differences in severity of cracking not observed at the milled surface but present below at these two locations could contribute to higher pressures in the subgrade than in the base layer. This would not have occurred had the gauges been placed one on top of the other, separated only vertically.

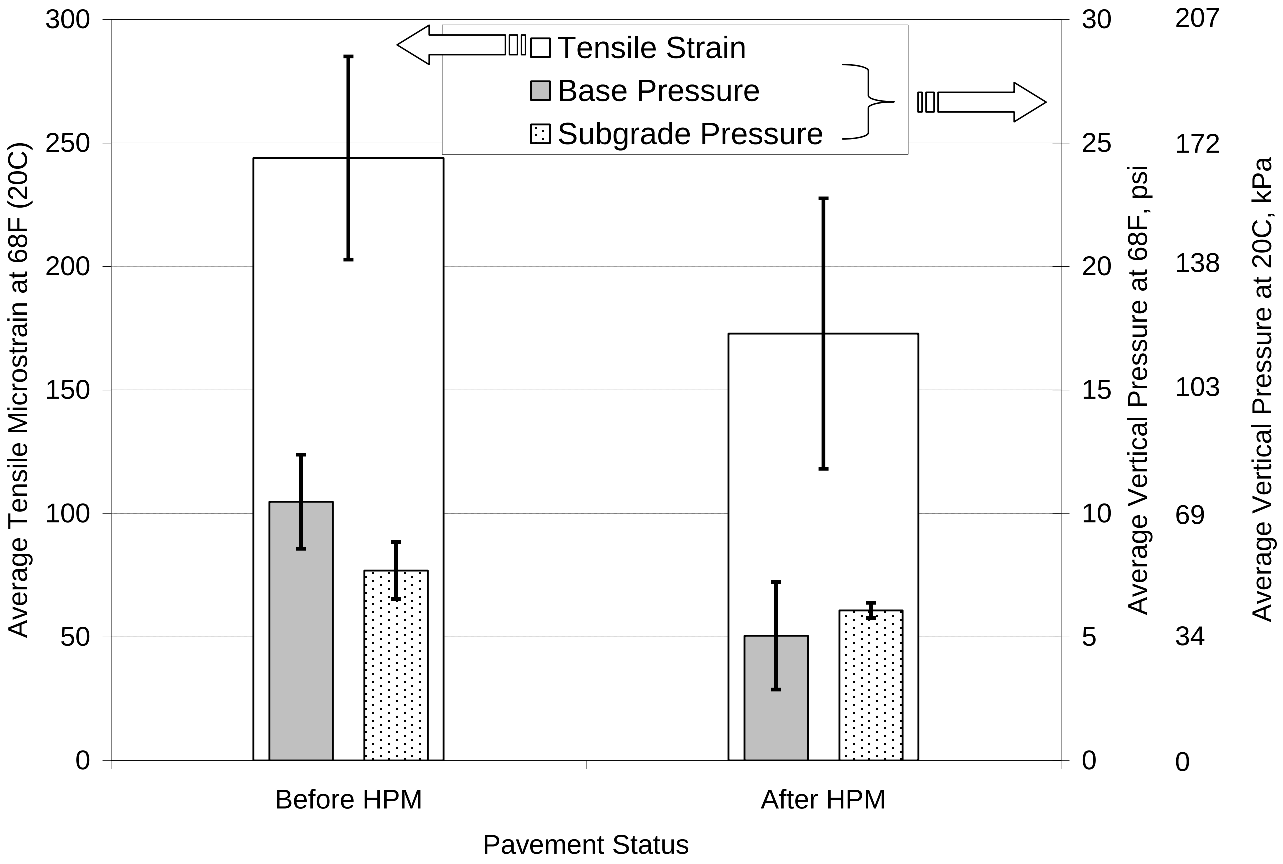

FIGURE 11 : Pavement responses at 20 °C

5. CONCLUSIONS AND RECOMMENDATIONS

This paper documented the use of HPM mix in a mill-and-inlay application on a badly distressed pavement at the NCAT Pavement Test Track. Based on the data presented above, the following conclusions and recommendations are made:

1. No significant problems were encountered during the production and placement of the HPM rehabilitation layers.
2. Traffic applied to the HPM rehabilitation has now surpassed the level needed to completely fail the original conventional rehabilitation, with no indication that another failure is pending. Rut depths are less than 3 mm, roughness has not changed since the HPM was placed, and no cracking has been observed.
3. The HPM had an immediate and statistically-significant impact on the asphalt modulus of the pavement. An approximate 55% modulus increase was noted with reduced section-wide variability in asphalt modulus. The coefficient of variation went from 47% in the "before HPM" condition to 26% after the HPM was placed.
4. The original overlay at the beginning of the 2009 experiment did not appear effective in terms of reducing pavement strain as shown by a general increase through May 2010.
5. The HPM had statistically-significant impacts on measured asphalt strain, base pressure and subgrade pressure. Strains normalized to 20 °C were reduced by 29%, aggregate base pressure was reduced 51% and subgrade pressure was reduced 21%. In the context of mechanistic-empirical pavement analysis, these reductions are key to good performance of the section.
6. HPM mixes may be an effective rehabilitation option on roads where high strains are expected and increasing pavement thickness is not an option. They may also be useful for preventing the reflection of severe distresses as well as for preventing rutting in heavy, slow traffic applications.
7. Further monitoring of the section is recommended, through the end of this experiment and possibly into the next test cycle in 2012, to fully validate these findings.

7. ACKNOWLEDGEMENTS

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