PLANT MIX ADDITIVE USED TO PRODUCE BRIDGE DECK WATERPROOFING MATERIALS AND OTHER HIGH PERFORMANCE ASPHALT PAVEMENTS

Geoffrey Michael Rowe[1], *Phil Blankenship*[2], *Doug Zuberer*[3]
[1]*Abatech, Inc., Blooming Glen, USA*
[2]*Asphalt Institute, Lexington, USA*
[3]*Chase Construction Products, Westwood, USA*

ABSTRACT

Plant mixed modifier (PMM) has been used for the past 25-years to produce waterproofing asphalt materials for bridge deck applications as a polymerized "Dry Mix" modifier. These offer significant advantages over conventional polymer modified binders since much high polymer loading can be used in the final material without the risk of storage separation and/or pumping and handling issues associated with these high polymer loads. However, with the advent of Superpave it has become the norm for many specifying agencies to include the Superpave binder specification tests as "performance related" controls for the specification. Unfortunately, with plant mix additives it is not possible to obtain a sample of the binder in the conventional manner that occurs with the use of PG binders thus making this route for quality assessment not feasible. Nevertheless, it is possible to evaluate mixture performance using a suite of tests that relate to low-temperature cracking, fatigue performance and permanent deformation, thus capturing the same end performance requirements considered in the binder but by testing the mixture. Conceptually, this is better since mix tests should more closely relate to field performance than binder tests. The use of performance tests to develop rational specification parameters is discussed. Recommendations are made that could form the basis for a performance related specification for these materials when used in such as bridge decks, race tracks, airports, ports, intermodal facilities and other high stress applications as an alternative to other modified materials.

Keywords: Plant mixed modifier, performance related testing, thermoplastic polymers

1. INTRODUCTION

Bridge deck surfacings have made use of the highest quality asphalt materials to meet the specialized requirements that are needed. Traffic on bridge decks is constrained between physical limits to a much greater extent than typical highways resulting in a much greater degree of channelization of traffic flow. This in turn results in a much greater degree of loading in wheel tracks that can result in deformation if a material is not designed with extreme care. In addition, these materials have to be waterproof to ensure that salts and other harmful effects of water penetration do not result in deterioration to the bridge structure. Flexibility is required to cope with the movements that occur on different types of bridge decks.

The need to provide waterproofing results in the HMA material requiring a very low void content, typically in the range 1 to 2%. This generally ensures that the hydraulic conductivity of material will be less that $1x10^{-7}$ cm/sec when assessed with the ASTM D5084 (1) test method. This low void requirement would result in a material, if made with conventional asphalt binder, which would be more prone to deformation. Consequently, the adopted materials have made extensive of thermo-plastic properties which results in material that exhibit behavior that approximates a visco-elastic solid at normal working temperatures.

Considerable experience has been obtained with a system of modification referred to as “Rosphalt” for approximately 25 years. This is a thermo-plastic PMA that is typically added at a rate of 45 pounds per ton of hot mix. The material has an excellent performance history but the data obtained over time has been largely based upon quantification of empirical properties and performance history. In recent years it has become increasingly important to evaluate material properties in terms of fundamental characteristics since these are required by specifying agencies and are an essential part of risk reduction with assessment of material performance. While asphalt binders can be assessed by testing in accordance with PG grade tests, AASHTO M320 (2), these cannot be simply performed on samples taken from site when evaluating mixture performance made with a plant-mix additive. Consequently, mixture evaluations have included a range of tests implemented by AASHTO which will become the norm in testing laboratories as the implementation of the new pavement design methods being developed by AASHTO take place. These same tests can be used equally to assess these materials used on bridge decks. Test in the Asphalt Pavement Analyzer (APA) wheel tracking device (AASHTO TP63 (3)), Indirect Tensile device (low temperature cracking) (AASHTO-T322 (4)) and fatigue device (AASHTO-T321 (5)) assess the performance. This same issue of implementing plant mix additives exists in surfacings for highway materials. The problem of evaluation of plant mix modifiers is not confined to Rosphalt since manufactures produce modifiers such as pellets added directly to the hot mixes which have the same implementation problems. For example SBR latex which has been used to modify asphalt materials for a significant number of years. The use of the mixture performance tests thus allows these materials to be implemented in a meaningful manner, in which the measure of performance is on the mixture – a closer stage of production to the completed road pavement, rather than just the binder. In addition to discussions regarding implementation, some suggestions are made with regard to suitable specification parameters for a bridge deck material.

2. PMM ASPHALT MIX PERFORMANCE REQUIRMENTS

The need for high performance materials for use in bridge deck surfacing is well established (Hicks (6)) and asphalt materials have been used for over 100 years in prominent bridge structures, Boorman (7). Other high stress sites such as airports, ports, race tracks and intermodal facilities often place special demands upon the materials used. The sites have typically been surfaced with specialty materials which have included Mastic Asphalt, Guasphalt, Hot Rolled Asphalt, Asphalt Concrete and Epoxy Asphalt to name a few. Some of these materials have good water-proofing properties such as Mastic Asphalt and Guasphalt but if used with conventional binders these materials can have significant problems with deformation performance in high temperature locations or used with very heavy traffic. Other systems such as Hot Rolled Asphalt, Epoxy Asphalt and Asphalt Concrete have been traditionally used with other layers which impart water-proofing properties to the combined layers, for example if used over bridge decks.

Bridge decks have traffic which is generally channelized into narrower widths thus promoting application of repeated loading over a narrower width. In addition, steel decks, will result in a greater need for flexure and fatigue performance. Further, to protect the decks from salt and the harmful effects of water intrusion it is important that the deck surfacing materials have a very low void content thus rendering effective impermeability.

With conventional asphalt materials high deformation resistance results partially from a good aggregate skeleton in the mixture. However, when the void content is reduced to less than 3% the aggregate skeleton is significantly reduced. The thermo-plastic PMA effectively modifies a standard visco-elastic binder with liquid like properties into a binder which has properties that are closer in performance to a visco-elastic-plastic solid material.

The performance requirements of a mixture for a bridge are therefore summarized by three main requirements, flexibility, deformation resistance and low hydraulic conductivity. Flexibility is considered in two manners; 1) resistance to load associated cracking, and 2) resistance to thermally induced fatigue cracking.

Often with material little data is available that defines the performance in a structured manner. For fatigue, if a detailed evaluation is considered, it is preferable to construction a fatigue curve in which life is expressed as a function of strain level. Alternatively life can be assessed at a single strain level.

Thermal cracking performance is assessed according to mixture performance tests in the IDT test device and this is related to the climatic data for a particular location. Deformation properties at high temperature are considered using wheel tracking tests at high pavement temperatures. Fatigue performance requirements for materials vary with different type of bridge decks, resulting in differing fatigue and flexibility demand. Generally, the flexure that occurs on concrete bridge decks is relatively small when compared to steel decks and quite different demands on the material performance exist when comparing the two types of deck response. Typically steel bridge decks can have a wide range of strain response as illustrated by the strain gauge results shown in Figure 1 which is the response to a 45-ton truck on an orthotropic steel deck which was instrumented in manner to capture various strains at critical locations in the deck (De Backer, (8)). The maximum magnitude of strain is approximately 500με in this figure. Medani (9) conducted detailed Finite Element analysis of an orthotropic steel deck bridge to study the need for correct modeling to understand stress and strain states that occur in the deck and asphalt materials. The response under a 14.5 ton duel wheel load is illustrated in Figure 2 with maximum tensile strains around 900με. In other work, for example that conducted by Houel et al. (10), where specialized devices have been fabricated to conduct tests that closely resemble the geometry of an asphalt material indicates initial strain amplitudes in the range 500 to 1500με. The evolution of damage in this more sophisticated device appears similar to that which would be expected in a controlled load bending beam fatigue test.

In the USA data collected by CAIT (11) for a study for materials laid on an orthotropic bridge deck in New York State used a value of 900με to evaluate materials in a four point controlled strain bending beam test. It should be noted that the materials being used in bridge decks tend to have a fatigue relationship which can be typically represented by a log-log relationship between tensile strain and fatigue life. While different agencies have used differing values for the evaluation of materials we would note that the performance of the materials in steel deck structures would suggest that values of strain are generally below 1,000με. Consequently, for thermo-plastic PMA materials we have generally adopted a standard testing level of 750με since most of the current DOT specifications have adopted this value. In addition, this value is consistent with the experience gained by others as discussed above. Life at other strain values can be estimated by fatigue lines produced by testing the materials at different strain levels.

For high stress applications such as race tracks and airports the deformation performance of the material is critical as well as the surface durability. The durability can be achieved with the very dense mixtures as used on bridge decks but performance must be assessed for deformation and damage by fuel. Consequently, other testing conducted by the research team has included assessment of the fuel resistance of the materials. This aspect is particularly important for some locations, such as airports and race-tracks, where the risk of fuel spillage is quite high.

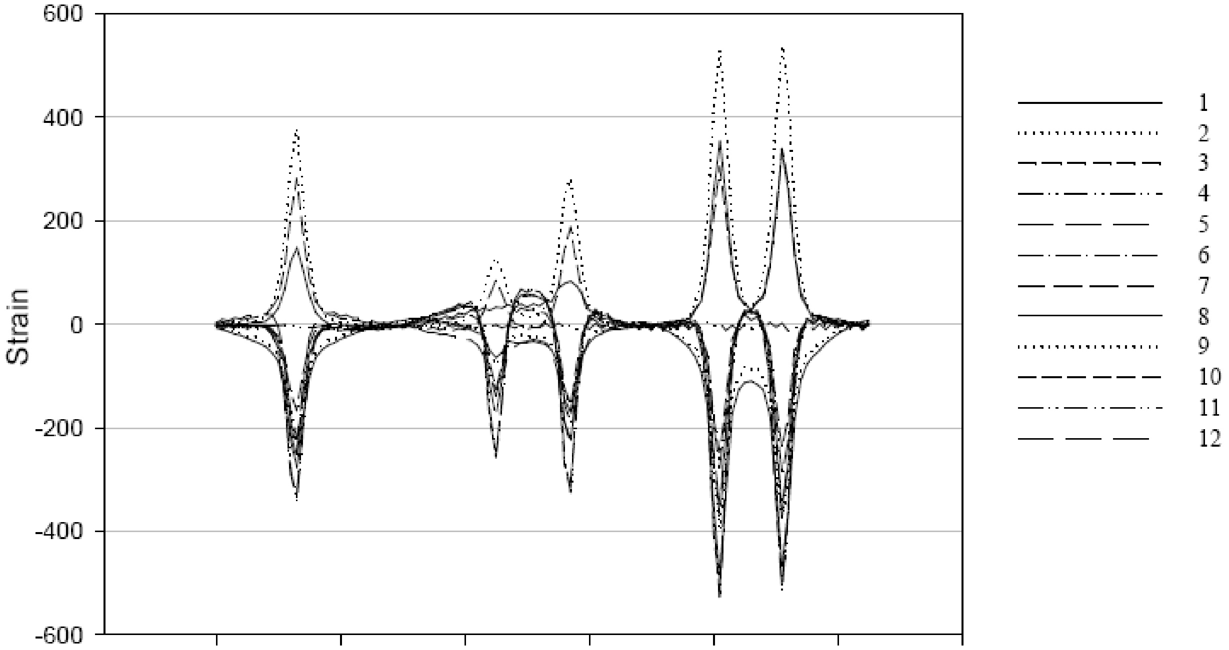

Figure 1: Strain response of orthotropic steel deck bridge (after De Backer et al. (11))

3. MATERIALS EVALUATED

The thermo-plastic PMA is supplied in a powder form and added to the asphalt mixture at a rate that approximates 2.25% of the total mixture. A typical mixture suitable for modification will have a 10mm (⅜-inch) maximum aggregate size and the resulting mixture will have a void content when compacted less than 2% air voids. The material is supplied in various forms but generally either in polyethylene bags or tanker load. Bag form is generally preferred for batch plant and bulk supply in the form of tanker loads of the product is the preferred method with drum mix plants. The form of the powder used and a typical supply format is shown in Figure 3.

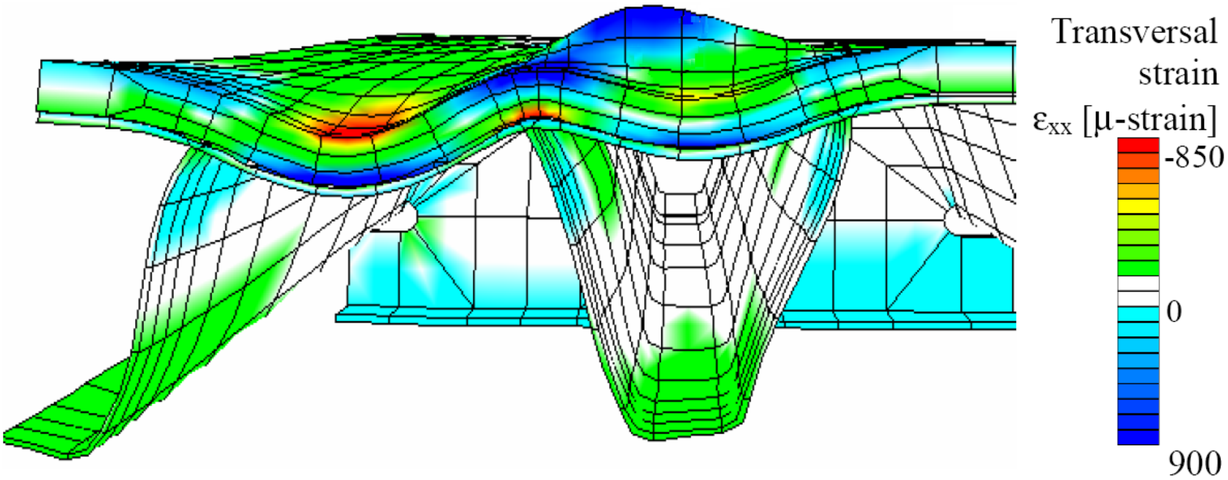

Figure 2: Deformed bridge deck (250x) with transversal strain under a 14.5 tons (3mm water-proof layer an 50mm mastic asphalt) (after Medani (12))

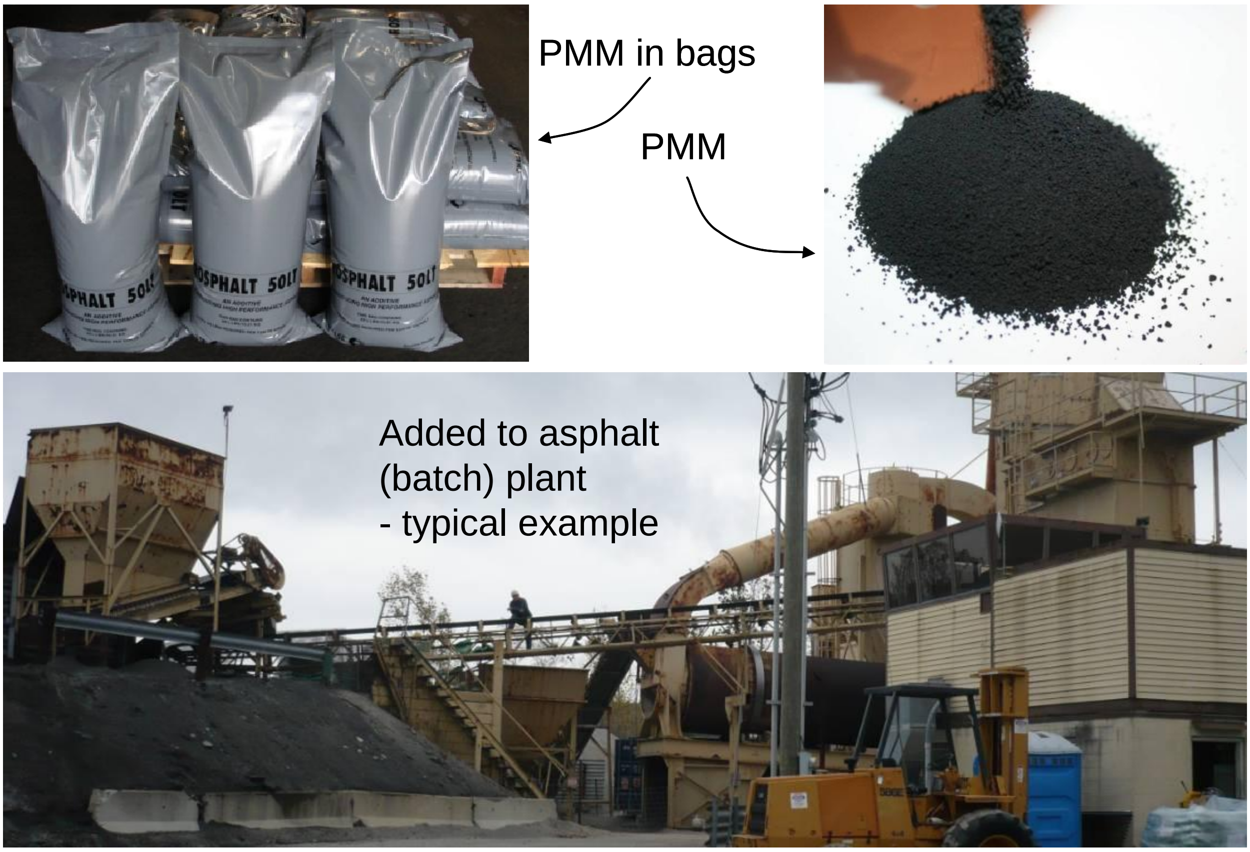

Figure 3: Example of supply form for PMM and typical addition to a batch mix asphalt plant with bags being added to a RAP feed and deposited directly into the pug-mill

For this paper various tests have been conducted using a standard mixture made with a NuStar PG64-22 grade binder mixed with a Trap Rock aggregate. These products are typical of those used in standard asphalt mixtures in the Northeast USA. The modification of a typical mixture such as this results in significant changes to the volumetric structure of the mixture (see Rowe et al. (12)) increasing the VMA and resulting in a larger volume of binder. The change in the aggregate structure results in a mixture that can not be considered to behave as a traditional asphalt concrete which relies upon much of its strength from an aggregate skeleton within the mix. Rather the material relies upon a minimal aggregate skeleton and more significantly upon the mastic of modified binder and fine aggregate which has approached a saturation level. This mastic is effectively working as a material which closely approximates visco-elastic solid structure between the larger aggregate particles thus preventing flow and deformation.

The modified materials have also been assessed from pavement cores with differing aggregate types to yield additional material samples so that field compacted materials can be compared to the laboratory prepared materials.

4. MIXTURE TEST METHODS

Hydraulic conductivity tests were performed using the procedures described in ASTM D5084 using the constant head method on specimens removed from the trial pavement areas and this data has previously been published (Rowe et al. (12)).

Low temperature properties were evaluated by indirect tensile creep tests at -40, -30 and -20°C, after which, specimens were strength tested at -30 C (AASHTO T322). The creep compliance data for the materials evaluated are shown in Figure 4 which also illustrates the master-curves developed at a reference temperature of -40°C. This data was then used with the method published in the SHRP A-357 report to estimate the thermal cracking (Lytton et al. (18)). From the fitted compliance mastercurve function an array of creep compliance have been generated values over an appropriate range of time to enable the calculations to be performed. Hopkins & Hamming’s (19) method is then used to obtain the numerical inverse of this array in the form of an array of Relaxation Function values. This is then fitted to a generalized hyperbolic power function to describe the relaxation modulus values, as follows:

$$E(t) = \frac{E_0}{\left(1 + (t/\lambda)^{\beta}\right)^{\frac{\delta}{\beta}}}$$

The software MONARCH (developed by Abatech) was used for this evaluation. The thermal Stress calculation involves the constitutive relation for a one-dimensional restrained structure subjected to a thermally induced strain which can be written as:

$$\sigma(\xi) = \int_0^{\infty} E(\xi - \xi') \frac{\partial(\varepsilon - \varepsilon^{th})}{\partial \xi'} d\xi'$$

where:

Reduced time $\xi = t/a_T$,

Thermal strain = ε^{th}

Shift factor = a_T

The shift factors and relaxation function obtained at step three are finally employed, with user-specified values of initial temperature, rate of cooling and linear thermal expansion, to enable numerical integration of the above equation. The thermal stresses versus temperature thus computed are compared with observed fracture strengths versus temperature, and if possible a critical cracking temperature is interpolated as shown in Figure 5. This data shows that the predicted critical cracking temperature computed for these various projects varies from -28 to -38°C, with an average performance of -33°C. The performance grade of the binders used in these evaluations was -22°C and consequently the improvement in low temperature performance ranged from 6 to 16°C. This represents a minimum of 1 grade improvement to as high as nearly three grades of improvement at the low end of the performance spectrum.

Fatigue testing was conducted using a bending beam test (AASHTO-T321) which was continued beyond the 50% reduction in stiffness thus enabling analysis with both the ASSHTO method and ASTM D4760 (20). For this testing beams were fabricated using the kneading compaction device and beams then sawed from the slabs of resulting mixture. The slabs were compacted to a void content of 1 to 2% for this work. The fatigue of the response has then been compared to conventional materials. At a strain level of 750με the performance is increased from 2,000 load cycles to over 2,000,000 load cycles.

Permanent deformation tests were conducted using both laboratory prepared specimens and specimens removed from the pavement structures by coring. Initially, in the study the Hamburg Wheel Tracking (22) test was used at 50°C but it was decided that it would be more prudent to conduct tests at the high PG grade temperature. Since the majority of states in which the thermo-plastic PMA materials are used tend to make use of the Asphalt Pavement Analyzer (APA) this was adopted for testing of cores from various sections. Tests were conducted at 64°C in this device and typically very low deformation rates were noted. A typical illustration of data obtained is given in Figure 7 below.

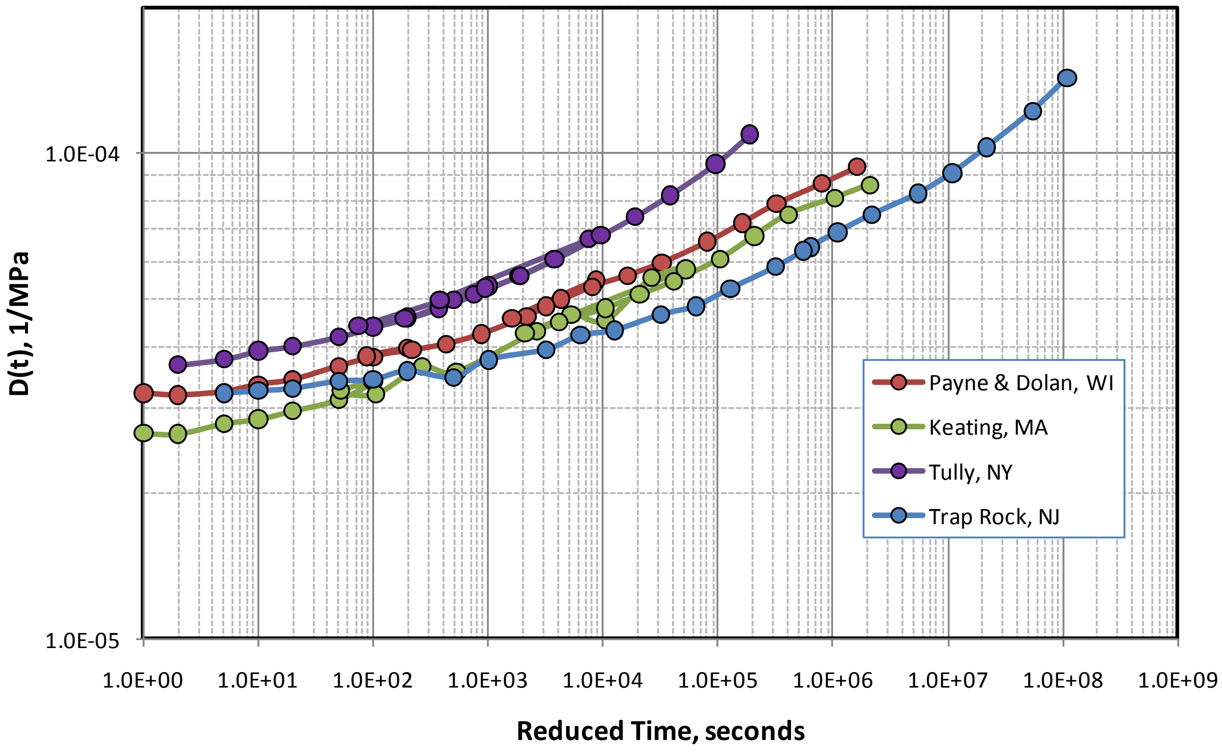

Figure 4: Creep compliance data obtained from core and gyratory compacted specimens

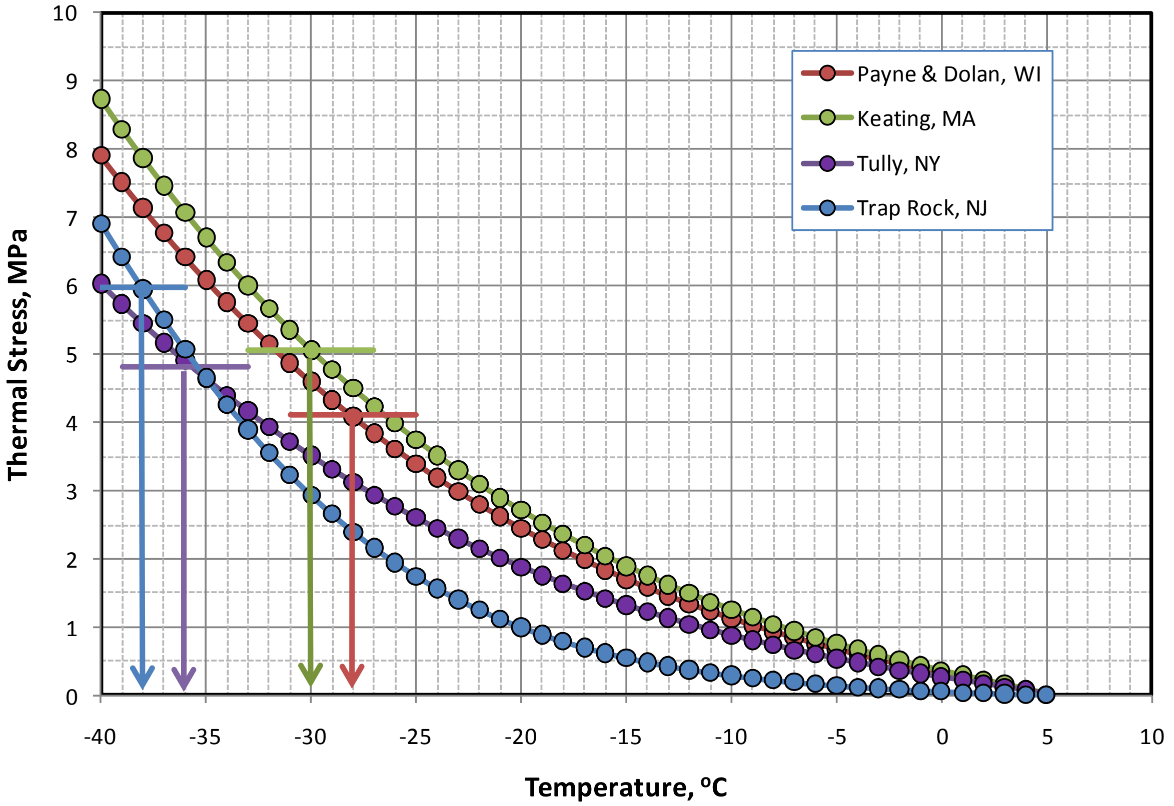

Figure 5: Estimated thermal stress for various mixes, horizontal lines represent tensile strength evaluated at -30°C

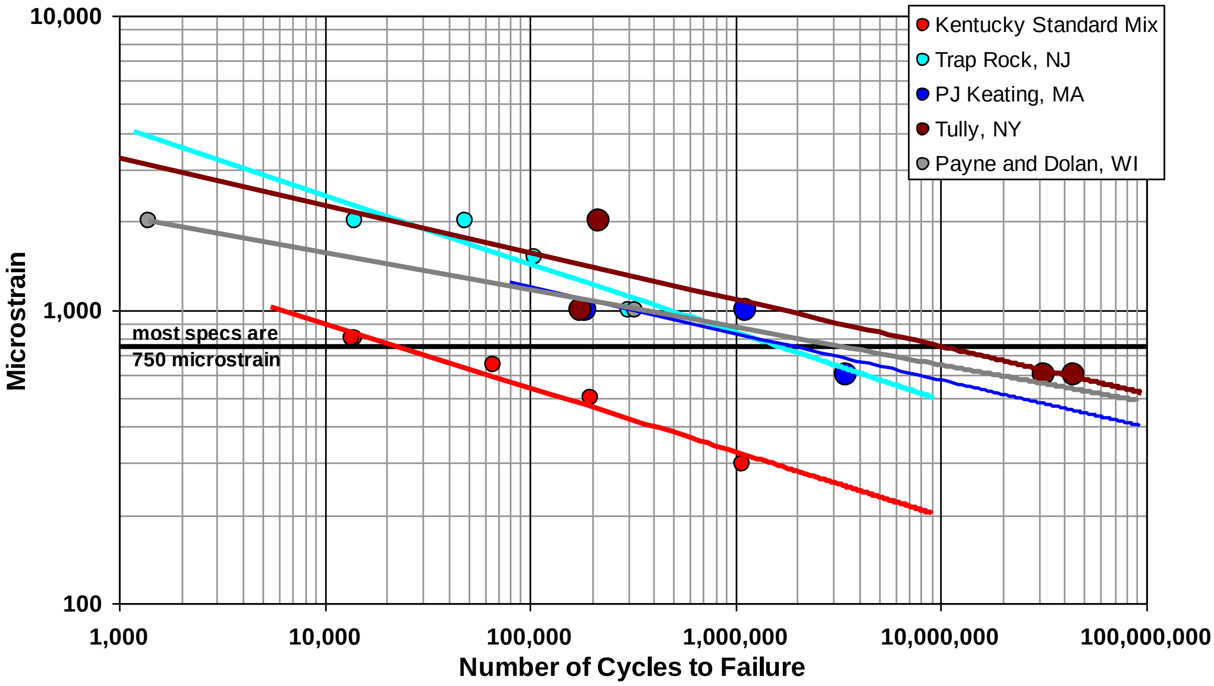

Figure 6 Fatigue performance of various thermo-plastic PMA compared to conventional HMA manufactured with PG64-22 binder

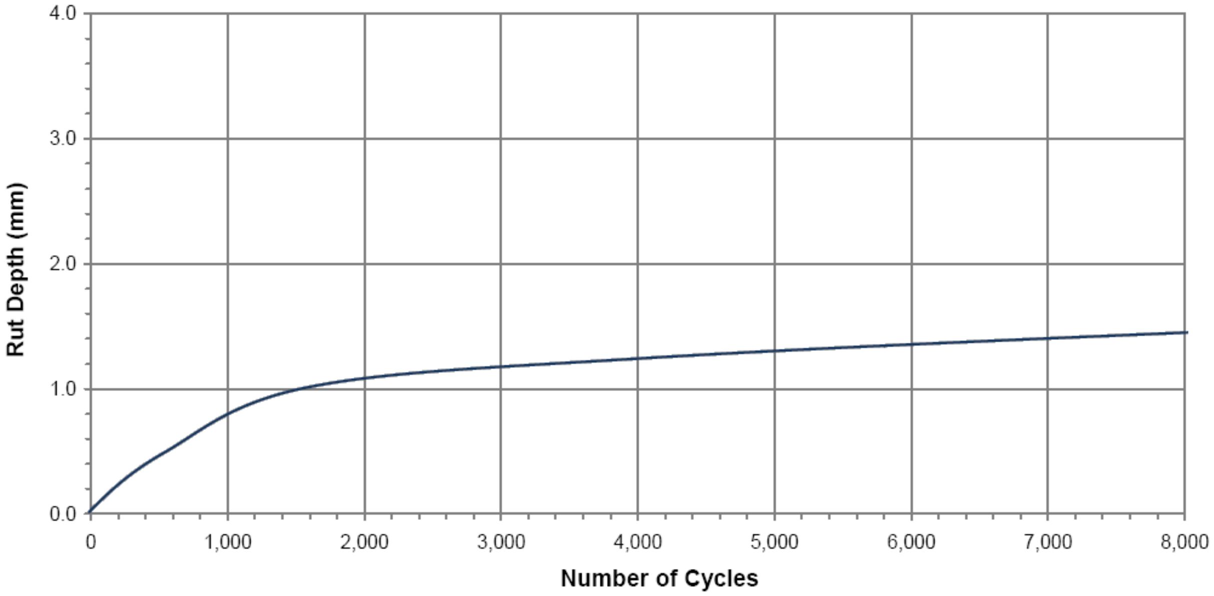

Figure 7 Typical APA performance of core specimen made with thermo-plastic PMA

The fuel resistant specification requires compacted mix samples to be immersed in jet fuel for 24 hours [soak test] and the average percent weight loss of Marshall specimens must be less than 1.5 percent. Laboratory tests have shown that a neat asphalt mixture test specimen will experience a weight loss in excess of 10 percent. The data evaluated for various PMA mixtures tested between 2005 and 2011 show a weight loss of 1.02 to 1.20%. Typical examples of Marshall specimens after testing are shown in Figure 8. These mixtures have been successfully adopted in locations that require this high degree of fuel resistance such as race-tacks and airports.

Figure 8: Typical performance of Marshall cores made with asphalt mix with plant mix additive after soaking in Kerosene for 24-hours

5. DISCUSSION

The performance of the thermo plastic PMA modified material compared to a conventional asphalt concrete material was evaluated at two specific stages of the work conducted; 1) mix design and 2) with material placed in paving trials. In addition, we have compared the data obtained with other historical data collected by PRI Asphalt Technologies and CAIT (11). The improvement in fatigue is supported by observations of performance on steel structures such as the George Washington Bridge, New York were material that was placed in the 2006 is still performing in a satisfactory manner in one of the most heavily trafficked bridges in the world with approximately 1,000,000 vehicles passing over the structure every month. Based upon these observations a reasonable specification requirement for the performance of materials for orthotropic steel bridge decks would be the requirement to achieve 1,000,000 load applications at a 750 microstrain level. For concrete decks the requirement for flexure is lower and this value could be considerably reduced. The stiffness obtained from the creep test was used to calculate the estimated stresses in the mixture when subjected to a standard cooling rate. The temperatures are significantly lower than that of the unmodified binder which was graded as a -22. The material characteristics that impacted this calculation significantly are the lower stiffness and the high tensile strength of the materials of that the thermo-plastic PMA achieves. While a modification level of 45lbs/ton of mix results in a minimum improvement of one PG grade at the low temperature part of the specification it is noted that the average improvement equates to nearly 2-grades.

The deformation performance of asphalt materials is very difficult to assess due to the complex interaction that exist between loading speed, stress applied, state of confinement of test specimens and other factors. Consequently, many agencies prefer to evaluate materials in wheel tracking experiments that appear to be intuitively representative of the actual loading on site. In the work with Rosphalt materials a wide variety of wheel tracking experiments have been conducted. Lai (20) assessed the performance of the material in the Georgia Wheel Tracking (GWT) for use in Racetracks whereas Mallick et al. (21) studied the by conducting tests in a “model mobile load simulator.” More recently, we have extended this data set by performing tests in the Asphalt Pavement Analyzer (which is the commercial development of the GWT) and the Hamburg Wheel Tracking (HWT) tests (22). The HWT test was conducted on a laboratory prepared specimen at 50^{o}C in the “wet condition” with a total deformation of 6.2mm after 20,000 load passes. The result in the APA (AASHTO TP63 (13)) on actual cores taken from the pavement areas gave an average deformation of 2.4mm at 8000 cycles (100 psi, Load - 100 lbs, test temperature 64^{o}C). Both these results indicate that the material has a good propensity to withstand permanent deformation. The key parameter that results in this excellent performance is the modification of the binder that results in practically all the strain associated with loading is recovered.

6. SUMMARY

The evaluation of the thermo-plastic PMA as an alternate bridge deck waterproofing system has required extensive laboratory and field evaluation. The key functionality requirements after the material has been placed are the ability of the material to act as a water-proofing layer, demonstrate good flexibility and resist permanent deformation. The modification achieves all three of these performance criteria via a unique “dry-process”. Each of these requirements relies upon a characteristic of the mixture or binder modification to achieve the desired functionality. The testing and evaluation of these materials can be performed rapidly with mixture specimens produced within the laboratory environment and verified by testing of field samples. Standard test methods now exist for low temperature cracking, fatigue performance and evaluation of rutting potential. It is the authors’ view that mixture tests provide a more meaningful evaluation and assessment of future performance since the correlations and calculations that rely on binder and aggregate properties are simply not needed. For achievement of adequate performance on high performance sites we have typically recommended the minimum test parameters as follows:

- Fatigue life, ASTM D4760 - $\geq$1,000,000 cycles, 20^{o}C, $750\mu\varepsilon$.
- Low temperature performance, AASHTO TP9, $\leq$-30^{o}C.
- Permanent deformation, AASHTO TP 63 - $\leq$10mm, 8,000 cycles, 64^{o}C.

- Hydraulic conductivity, ASTM D-5084 - $\leq 1 \times 10^{-7}$ cm/sec.
- Fuel resistance (proposed FAA methods) - ≤5.0%.

The use of plant mix additives allows HMA manufactures increased flexibility when producing materials for multiple projects in that:

- No liquid hot storage tanks are needed.
- No minimum amount of modified binder is needed.
- Significantly higher modification levels can be used (normally limited by pumping viscosity).

This method offers significant additional benefits of ease of maintenance and rapid construction time and can assist with the need for effective project delivery in today’s market.

REFERENCES

1 ASTM, “*Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*,” Test method ASTM D5084, ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, USA.

2 AASHTO, “*Standard Specification for Performance-Graded Asphalt Binder*,” Materials Standard M320, American Association of State Highway and Transportation Officials.

3 AASHTO, “*Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer (APA)*,” Test Procedure - TP63-03, American Association of State Highway and Transportation Officials.

4 AASHTO, “*Standard Method of Test for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device*,” Test Procedure - T322, American Association of State Highway and Transportation Officials.

5 AASHTO, “*Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending*,” Test Procedure - T321, American Association of State Highway and Transportation Officials.

6 Hicks, RG., Dussek, I.J. and Siem, C., “*Asphalt Surfaces on Steel Deck Bridges*,” Transportation Annual Meeting, Paper 00-0389, Washington, D.C., 2000.

7 Boorman, T.H., “*Asphalts, Their Sources and Utilizations, Asphalt for Dustless Roads, Recent Improvements in Asphalt Industries*,” Comstock, New York, 1908.

8 De Backer, H., Outtier, A. and Van Bogaert, P., “*Alternatives for Bridge Surfacings with Orthotropic Plated Deck: A Fatigue Point of View*,” Foundations of Civil and Environmental Engineering, No. 11, Poznań, 2008.

9 Medani, T.O., “*Design Principles of Surfacings on Orthotropic Steel Bridge Decks*,” University of Delft, PhD Thesis, 2006.

10 Houel, A., N’Guyen, T.L. and Arnaud, L., “*Monitoring and designing of wearing courses for orthotropic steel decks throughout the five-point bending test*,” Advanced Testing and Characterization of Bituminous Materials – Loizos, Partl, Scarpas & Al-Qadi (eds), Taylor & Francis Group, London, ISBN 978-0-415-55854-9, 2009.

11 Center for Advanced Infrastructure Testing (CAIT), “*The Advanced Characterization Testing of the Port Authority of NY/NJ’s Hot Mix Asphalt Materials - Rosphalt Material Test Results*,” Report submitted to The Port Authority of NY/NJ, Materials Engineering Division, Port Authority Technical Center, 241 Erie Street, Jersey City, New Jersey. 2006.

12 Rowe Blankenship and Zuberer

13 Buchanan, S., “*SHRP Asphalt Grading*,” Report on testing by National Center for Asphalt Technology, October, 1999.

14 ASTM, “*Standard Test Method for Multiple Stress Creep and Recovery (MSCR) of Asphalt Binder Using a Dynamic Shear Rheometer*,” Test method ASTM D7405 - 10a, ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, USA.

15 ASSHTO, “*Multiple Stress Creep and Recovery Test of Asphalt Binder Using a Dynamic Shear Rheometer*” Test Procedure - TP70, American Association of State Highway and Transportation Officials.

16 D’Angelo, J., Kluttz, Robert Q, Dongre, Raj, and Stephens Keith., “*Revision of the Superpave High Temperature Binder Specification: The Multiple Stress Creep Recovery Test*,” Journal of The Association of Asphalt Paving Technologists, Vol. 76, pp. 123, 2007.

17 Rowe G.M., and Sharrock, M.J., "*Development of Standard Techniques for the Calculation of Master Curves for Linear-Visco Elastic Materials*," The 1st International Symposium on Binder Rheology and Pavement Performance, University of Calgary, Alberta, Canada, August 14 - 15, 2000.

18 Lytton, R.L., Uzan, J., Fernando, E.G., Roque, R., Hiltunen, D. and Stoffels, S., “*Development and Validation of Performance Prediction Model and Specifications for Asphalt Binders and Paving Mixes*,” Report SHRP-A-357, The Strategic Highway Research Program, Washington DC 1993.

19 Hopkins, I.L. and Hamming, R.W., “*On Creep and Relaxation*,” Jour. Appl. Phys., Vol.28, No.8, pp.906, 1957.

20 Lai, J.S., "*Assessment of the Suitability of Using Rosphalt-50 Modified Asphalt Mixes for Auto Race Track Pavement Surface*," Report submitted to Royston Laboratories Division, Chase Corporation by Pavtec Engineering Technology, Imc, Georgia, July 1996.

21 Mallick, R.B. and Bergendahl, J.A., "*An Evaluation of Rutting and Shoving Potential of, and Chloride Diffusion through Hot Mix Asphalt (HMA) With Rosphalt*," Civil and Environmental Engineering Department, Worcester Polytechnic Institute, April 2004.

22 AASHTO, "Test Method for Hamburg-Type Wheel Tracking," AASHTO Test T324, American Association of State Highway and Transportation Officials.