Volume 85

Asphalt Paving Technology 2016

Journal Of The Association Of Asphalt Paving Technologists

Indianapolis, Indiana
March 13–16, 2016

Association of Asphalt Paving Technologists

DEStech Publications, Inc.

Table of Contents

TECHNICAL SESSIONS

CD TABLE OF CONTENTS

In addition to the papers listed above, the following items are also included in the CD

Long-Term Aging of Asphalt Mixtures

Fan Yin[a], Edith Arámbula-Mercado[b], Amy Epps Martin[a], David Newcomb[b], Nam Tran[c]

[a]Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas 77843

[b]Texas A&M Transportation Institute, College Station, Texas 77843

[c]National Center for Asphalt Technology, Auburn, Alabama 36849

ABSTRACT. Aging of asphalt mixtures occurs during production and construction and continues throughout the service life of the pavement. Although this topic has been studied extensively, recent changes in asphalt mixture components, production parameters, and plant design have raised a need for a comprehensive evaluation that considers the impacts of climate, aggregate type, recycled materials, WMA technology, plant type, and production temperature. In this study, field cores were acquired from seven field projects at construction and several months afterwards, and raw materials were also collected for fabricating laboratory specimens that were long-term oven aged (LTOA) in accordance with selected protocols. The resilient modulus and Hamburg wheel tracking tests were conducted on both specimen types to evaluate the evolution of mixture stiffness and rutting resistance with aging. The concepts of cumulative degree-days and mixture property ratio were proposed to quantify field aging and its effect on mixture properties. Test results indicated that the LTOA protocols of two weeks at 140°F (60°C) and five days at 185°F (85°C) produced mixtures with equivalent in-service field aging of 7–12 months and 12–23 months, respectively, depending on climate. Finally, among the factors investigated in the study, WMA technology, recycled materials, and aggregate absorption exhibited a significant effect on the long-term aging characteristics of asphalt mixtures, while production temperature and plant type had no effect.

KEYWORDS: aging characteristics, stiffness, rutting resistance, mixture components, production parameters.

The oral presentation was made by Fan Yin.

This paper has also been published in *Road Materials and Pavement Design*© 2016 Taylor & Francis. The article is available online at:
http://dx.doi.org/10.1080/14680629.2015.1266739

1.0 Introduction

The stiffening of asphalt mixtures with time due to volatilization, oxidation, and other chemical processes is referred to as aging. This occurs due to the heating of the binder during production and construction in the short-term and due to oxidation with time over the long-term throughout the service life of the pavement. The ability to simulate field aging of asphalt binders and mixtures has been studied extensively, and laboratory aging procedures including the use of Pressure Aging Vessel on asphalt binders and laboratory long-term oven aging (LTOA) protocols on compacted asphalt mixtures have been adopted for use in binder specifications and mixture design. Additionally, field aging of asphalt mixtures has been assumed to be relatively consistent in the past, and acceptable correlations have been established between field aging and laboratory LTOA protocols (Bell et al., 1994; Brown and Scholz, 2000; Glover et al., 2005; Harrigan, 2007; Epps Martin et al., 2014). However, this occurred at a time when the amount of recycled materials was relatively low, warm mix asphalt (WMA) was not common, and plant production temperatures were fairly consistent.

In the last three decades, changes have occurred in asphalt mixture components, mixture processing, and plant design, including increased use of polymer modifiers, increased use of recycled materials, the advent of WMA, and drum mix plants (DMP) replacing batch mix plants (BMP). Although these changes are beneficial for economic, environmental, and technical reasons, they have raised the need to review the practices on how asphalt mixtures are designed and evaluated. Therefore, there is a need to further evaluate the long-term aging characteristics of asphalt mixtures that considers the impacts of climate, aggregate type, recycled materials, WMA technology, plant type, and production temperature.

The objectives of this study are to: (1) develop a correlation between field aging (i.e., one to two years after construction) and laboratory LTOA protocols that accommodates various mixture components and production parameters, and (2) identify factors with significant effects on the long-term aging characteristics of asphalt mixtures. Construction and post-construction cores were acquired from seven field projects as representatives of field aging. In addition, raw materials including aggregates, asphalt binders, and recycled materials were also obtained from the same field projects for fabricating laboratory-mixed laboratory-compacted (LMLC) specimens in accordance with selected LTOA protocols. The resilient modulus (M_R) test and Hamburg wheel tracking test (HWTT) were included in the study to investigate the effect of long-term aging of asphalt mixtures.

This paper first provides a brief literature review on the long-term aging of asphalt mixtures in the field and laboratory. Then, the experimental design is described, followed by test results and data analysis. Finally, conclusions of the study and recommendations for future research are provided.

2.0 Background

Aging of asphalt pavements continues throughout their in-service lives, though at a lower rate compared to that occurring during production and construction. Therefore, it is important to account for the changes in asphalt mixture properties due to field aging when preparing laboratory samples for long-term performance testing. The standard practice for laboratory mix design of asphalt mixtures is to simulate field aging by conditioning compacted specimens for five days at 185°F (85°C) in accordance with AASHTO R 30. In the past few decades, studies have evaluated the effect of field and laboratory long-term aging on asphalt mixture properties and identified reasonable correlations between field aging and laboratory LTOA protocols. A brief summary of these studies is provided in Table 1.

As summarized in Table 1, previous studies have documented that field aging has a significant effect on mixture properties, and a number of factors have been identified to have an influence on field aging characteristics of asphalt mixtures, including pavement in-service temperature and time, mixture air voids (AV) and binder content, and aggregate absorption. Similar to field aging, laboratory LTOA protocols were able to produce asphalt mixtures with significantly increased mixture stiffness and rutting resistance as compared to those for unaged mixtures. In addition, the aging characteristics of asphalt mixtures were more sensitive to LTOA temperature than LTOA time. Finally, a variety of correlations between field aging and laboratory LTOA protocols has been proposed, and the differences among those correlations were likely due to the different binder or mixture properties investigated.

Despite the previous research efforts on long-term aging of asphalt mixtures, there are still several aspects that need to be fully addressed. For example, the quantification of field aging using pavement in-service time failed to account for the differences in construction dates and climates for various field projects; therefore, a better field aging metric is needed considering both pavement in-service temperature and time. Furthermore, it is essential to develop a correlation between field aging and laboratory LTOA protocols that encompasses the effects of aggregate absorption, recycled materials, WMA technology, plant type, and production temperature.

Table 1. *Previous research on long-term aging of asphalt mixtures.*

Reference	Long-Term Aging	Major Findings
Kemp and Predoehl, 1981	Field Aging	Air temperature, AV, and aggregate porosity significant effects
Kari, 1982		Pavement permeability and asphalt content significant effects
Rolt, 2000		• Exposure time and ambient temperature significant effects • Binder content, mixture AV, and filler content no effect

Reference	Long-Term Aging	Major Findings
Rondon et al., 2012		• Increased mixture stiffness, rutting resistance, and fatigue resistance for first 29 months of environmental exposure • Opposite trend observed between 30 and 42 months
Farrar et al., 2013		• Field aging not limited to the top 25mm of the pavement • Field aging gradient observed
West et al., 2014		• WMA less aging than HMA during production • Reduced difference between WMA vs. HMA with field aging • Equivalent binder true grade and binder absorption for WMA vs. HMA after two years of field aging
Morian et al., 2011	Lab Aging (3, 6, and 9 months at 60°C)	• Increased mixture E* and binder carbonyl area (CA) with LTOA • Binder source significant effect while aggregate source no effect
Azari and Mohseni, 2013	Lab Aging (2 days at 85°C 5 days at 85°C)	• Increased mixture resistance to permanent deformation with LTOA • Interdependence observed between STOA and LTOA
Tarbox and Sias Daniel, 2013	Lab Aging (2 days at 85°C 4 days at 85°C 8 days at 85°C)	• Increased stiffness with LTOA • Stiffening effect from LTOA: virgin mixture > RAP mixture • Global Aging System model > LTOA
Safaei et al., 2014	Lab Aging (2 days at 85°C 8 days at 85°C)	• Increased stiffness with LTOA • Reduced difference in stiffness for HMA vs. WMA with LTOA
Bell et al., 1994	Field vs. Lab Aging (4 days at 100°C 8 days at 85°C)	• STOA of four hours at 135°C = field aging during the construction process • Effect on mixture aging: LTOA temperature > LTOA time • STOA plus LTOA of four days at 100°C and eight days at 85°C = nine years of field aging in Washington State
Brown and Scholz, 2000	Field vs. Lab Aging (4 days at 85°C)	• Stiffness: LTOA of four days at 85°C = 15 years of field aging in the United States
Harrigan, 2007	Field vs. Lab Aging (5 days at 80°C 5 days at 85°C 5 days at 90°C)	• Significant field and laboratory aging • AV content effect on field aging • Five days at 85°C vs. seven to ten years of field aging: lab > field when AV < 8%; lab < field when AV > 8%
Epps Martin et al., 2014	Field vs. Lab Aging (1 to 16 weeks at 60°C)	• Increased stiffness with field aging and laboratory LTOA • Pavement in-service temperature effect on field aging • Stiffness: WMA = HMA, after six to eight months of field aging • Stiffness: STOA of two hours at 135°C for HMA and two hours at 116°C for WMA plus LTOA of four to eight weeks at 60°C = first summer of field aging

3.0 Experimental Design

This section provides an overview of the experimental design used in the study, including selection of field projects and materials, specimen fabrication procedures, laboratory tests, and research methodology.

3.1 Field Projects and Materials

Materials used in this study were from seven field projects (surface layers) located across the United States. The following factors were considered in order to include a wide spectrum of materials and production parameters: aggregate absorption, WMA technology, inclusion of recycled materials, plant type, and production temperature. For each of these field projects, construction cores and at least one set of post-construction cores were acquired from the surface pavement layers to represent field aging. In addition, raw materials including asphalt binders, aggregates, and recycled materials were collected for fabricating LMLC specimens. Table 2 provides a summary of these field projects in terms of mixture components and production parameters.

3.2 Specimen Fabrication

To fabricate LMLC specimens, aggregates and binders were heated to the specified plant mixing temperature and then mixed using a portable mixer. Afterwards, the loose mix was conditioned in the oven following the laboratory short-term oven aging (STOA) protocol of two hours at 275°F (135°C) prior to compaction in the Superpave Gyratory Compactor. The selected STOA protocol was able to simulate the volumetrics, stiffness, and rutting resistance of construction cores (Yin et al., 2015). Trial specimens were fabricated to ensure specimens were obtained with AV contents of 7.0±0.5%. To simulate long-term aging in the field, the short-term aged LMLC specimens were further aged after compaction in accordance with laboratory LTOA protocols of two weeks at 140°F (60°C), three days at 185°F (85°C) (only for two field projects), and five days at 185°F (85°C) prior to being tested for performance evaluation.

Table 2. *Summary of field projects.*

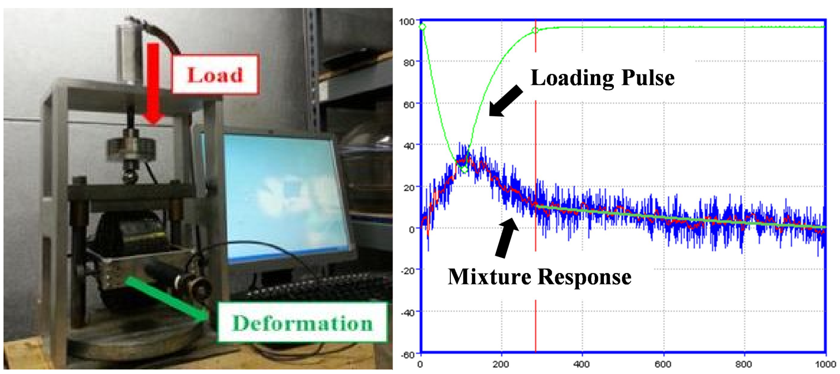
Project	Asphalt	Aggregate	Mixture	% RAP	% RAS	$T_{production}$	Factor
Texas	PG 70-22 PG 64-22	Limestone	HMA	-	-	325°F	WMA Technology Recycled Material
			HMA	15	3	325°F	
			Foaming	-	-	275°F	
			Evotherm	-	-	275°F	
			Evotherm	15	3	270°F	
New Mexico	PG 76-28 PG 64-28	Siliceous Gravel	HMA	-	-	345°F	WMA Technology Recycled Material
			HMA	35	-	315°F	
			Foaming	35	-	285°F	
			Evotherm	35	-	275°F	
Wyoming	PG 64-28	Limestone	HMA	-	-	315°F	WMA Technology Production Temperature
			Foaming	-	-	275&295°F	
			Evotherm	-	-	255&275°F	
South Dakota	PG 58-34	Quartize	HMA	20	-	310°F	WMA Technology
			Foaming	20	-	275°F	
			Evotherm	20	-	270°F	
			Advera	20	-	280°F	
Iowa	PG 58-28	Limestone (0.9&3.2% Absorption Capacity [AC]) Field Sand	HMA (0.9%AC)	20	-	295&325°F	WMA Technology Production Temperature Aggregate Absorption
			HMA (3.2%AC)	20	-	295&310°F	
			Foaming (0.9%AC)	20	-	265&295°F	
			Foaming (3.2%AC)	20	-	260&290°F	
Indiana	PG 64-22	Limestone	HMA (BMP)	25	-	305°F	WMA Technology Plant Type
			HMA (DMP)	25	-	300°F	
			Advera (BMP)	25	-	273°F	
			Foaming (DMP)	25	-	271°F	
Florida	PG 58-28	Granite (0.6% AC) Limestone (3.7% AC)	HMA (0.6%AC)	25	-	306°F	WMA Technology Aggregate Absorption
			HMA (3.7%AC)	25	-	308°F	
			Foaming (0.6%AC)	25	-	272°F	
			Foaming (3.7%AC)	25	-	267°F	

3.3 Laboratory Tests

The M_R test was conducted through repetitive applications of a compressive haversine load along the vertical diametral plane of cylindrical asphalt concrete specimens. The resulting horizontal deformations of the specimen were measured by two linear variable differential transducers (LVDT) aligned along the horizontal diametral plane. An environmentally controlled room at 77°F (25°C) was used for temperature conditioning and testing. The test equipment used to perform the measurements and the specimen setup are shown in Figure 1. M_R stiffness was measured per ASTM D7369 with external LVDTs aligned along the horizontal diametral plane (i.e., gauge length as a fraction of diameter of the specimen = 1.00). As expressed in Equation 1, the M_R stiffness was calculated based on vertical load, horizontal deformation, and the asphalt mixture's Poisson ratio.

$$M_R = \frac{P(\nu + 0.2732)}{t\Delta} \quad [1]$$

Where: M_R = resilient modulus of asphalt mixture;
p = vertical load;
υ = Poisson's ratio;
t = specimen thickness; and
Δ = horizontal deformation measured by LVDTs.



(a) *(b)*

Figure 1. *M_R test; (a) sample setup in loading frame, (b) data acquisition system.*

The HWTT (AASHTO T 324) is a laboratory test commonly used for evaluating rutting resistance and moisture susceptibility of asphalt mixtures. The test consists of submerging specimens in warm water at 122°F (50°C) and subjecting them to 52 passes of a loaded steel wheel per minute. Each of two replicate specimens was loaded for a maximum of 20,000 load cycles or until the center of the specimen deformed by 12.5mm per Texas Department of Transportation specification Tex-242-F. The HWTT equipment used to perform the measurements is shown in Figure 2.

Figure 2. *HWTT test equipment.*

For the HWTT rutting analysis, a novel method developed by Yin et al. (2014) was used in the study to discriminate asphalt mixtures with different rutting resistance, and the viscoplastic strain increment at the stripping number ($\Delta\varepsilon^{vp}_{SN}$) (i.e., rutting resistance parameter [RRP]) was employed as the HWTT rutting resistance parameter. As compared to the traditional rutting resistance measure of rut depth at a given number of load cycles, the RRP parameter isolates the viscoplastic strain during the creep phase and excludes any contributions from the post-compaction phase due to different specimen AV or due to stripping. The determination of the RRP is schematically illustrated in Figure 3, and the detailed calculations can be found elsewhere (Yin et al., 2014). Asphalt mixtures with lower RRP values are expected to have better rutting resistance than those with higher RRP values.

According to previous experience with the analysis method, early stripping had been frequently observed for short-term aged asphalt mixtures using softer asphalt binders when tested at 122°F (50°C), with the stripping number observed at less than 3,000 load cycles. These mixtures had a limited duration of the creep phase before stripping occurred, and as a consequence, the determination of the viscoplastic strain was not feasible. Therefore, in this study, the evaluation of mixture rutting resistance by the RRP value was only performed for asphalt mixtures having a stripping number greater than 3,000 load cycles (mixtures from Texas, New Mexico, South Dakota, and Florida field projects).

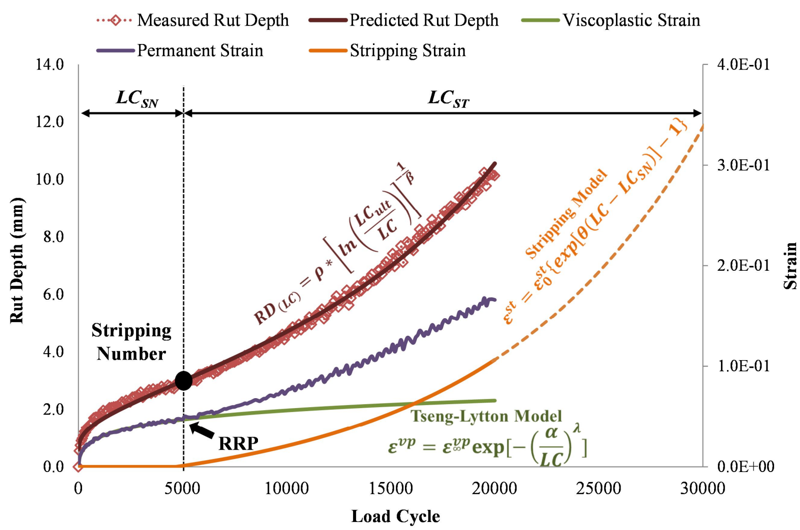


Figure 3. *Determination of HWTT RRP value.*

3.4 Research Methodology

Figure 4 presents the research methodology used in the study. Short-term and long-term aged asphalt mixtures (i.e., cores at various in-service times and LMLC specimens aged with different laboratory LTOA protocols) from seven field projects were tested to determine M_R stiffness and HWTT RRP values. The test results were analyzed to quantify the evolution of mixture stiffness and rutting resistance with long-term aging in the field and establish a correlation between field aging and laboratory LTOA protocols. In addition, comparisons in terms of M_R stiffness results were also performed to evaluate the effects of mixture and production factors on the long-term aging characteristics of asphalt mixtures.

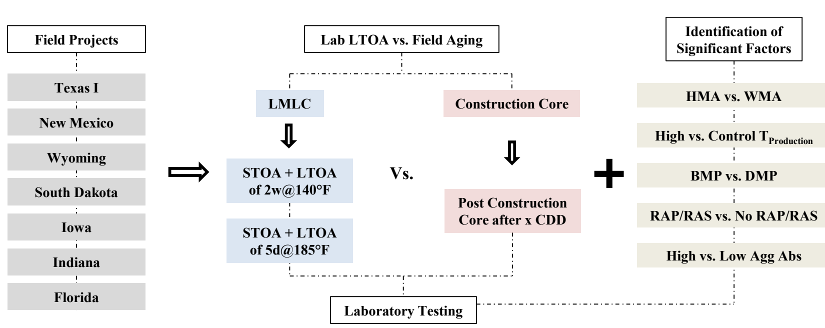


Figure 4. *Research methodology.*

Index
Contributors and Discussors

Underlined page numbers refer to formal papers and presentations. Other page numbers refer to discussion presentations.