Evaluation of Asphalt Cement Characteristics and Field and Lab Performance of High RAP Warm Mix Asphalt Using Hypertherm™ WMA Technology

Ryan S. Clark
Materials Performance Manager
Municipal Group of Companies
Bedford, Nova Scotia
Author, Presenter

Terry Hughes, P.Eng
Pavement Engineeer
New Brunswick DOT
Fredericton, NB
Co-Author

Jamie Weatherbee P.Eng
Group Leader – Geotech & Materials
Stantec Ltd.
Fredericton, NB
Co-Author

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Abstract

This paper evaluates the effects on the Performance Grade (PG) of liquid asphalt and on the mechanical properties of hot mix asphalt concrete when using Hypertherm Warm Mix Asphalt (WMA) modifier in high volume Recycled Asphalt Pavement (RAP) mixtures.

For a reconstruction project on New Brunswick Rte 10, asphalt binder characterization was performed in the mix design phase of the NBDOT HRB mix design, resulting in a required grade bump from PG 58-28 to PG 52-34 at a level of 30% RAP. During paving a 1 KM trial section of this project was paved with an identical mixture utilizing a PG 58-28 as the virgin binder and including Hypertherm™, a warm mix additive. The WMA-HRB was produced at 250˚F (120˚C), versus the 310˚F (155˚C) temperature of the conventional mixture.

The binder characterization of liquid asphalt extracted from the plant produced asphalt concrete showed extremely encouraging results. The WMA-HRB graded to PG 67-27, while the conventional HRB mixture graded to PG 78-23. This indicates that applying WMA in this manner not only successfully reduced aging of the asphalt binder during production, reducing the need for the typical grade bump required, but produced superior low temperature results than the conventional HRB mixture.

Data collected by fitting dynamic modulus master curves from the mixtures produced and rut information generated from plant mix produced samples seem to support the asphalt binder information very well. Further supporting performance testing of fatigue and low temperature cracking susceptibility will be performed to further investigate the relative performance of these mixtures.

1. Introduction

1.1 Background

The use of RAP in HMA is not new to the paving industry. In history, many factors determined the amount of RAP to be used; availability of recycled materials, cost of disposal in urban areas, and cost of HMA aggregates drove the decision for contractors and agencies to adopt HMA Recycling Programs. In early applications, it was generally believed that large proportions of RAP were needed to make a recycling program cost effective. Typically, milled asphalt was removed from the road, processed in some manner and re-introduced back into a central plant, classically a parallel flow drum plant, at proportions up to 50% and placed. As history also documents, there were many failures, and the industry embarked upon a series of restrictive specifications to prevent misuse of recycling technology.

Technological changes in the last 20 years have altered the outlook of HMA recycling. Plant technologies have improved significantly, as well as restrictions on emissions and asphalt binder rheology which generally stagnated or slowed the use of RAP throughout North America. The use of RAP at lower percentages was generally common in urban areas, where the disposal of RAP becomes difficult and expensive, but generally not cost effective in rural areas.

Fittingly, modern RAP programs have become highly technical, with most agencies requiring binder rheology verification at levels over 15% and processing RAP into multiple fractions becoming common. Common barriers to utilizing rap successfully at high percentages (30%+) remain the need to import soft binders which are uncommon in many locations, and overcoming high baghouse temperatures and emissions from having to significantly increase production temperatures for proper mixing and production.

Warm Mix Asphalt is loosely defined as any asphalt technology that allows producers to produce and successfully place HMA at temperatures lower than traditionally required by temperature-viscosity analysis. The recommended guidelines in industry require a production temperature reduction to at least 275°F (135°C), (the point at which light ends in the virgin liquid asphalt begin to burn off) to be considered WMA. [2,3]

WMA technology has expanded significantly in North America since the first trials in 2004-2005, and the number of technologies continues to grow exponentially. The classification of these technologies is changing as they become more accepted. Technologies can generally be grouped into four main categories. [1,6,7,9,13]

- Free Water Systems that are attached to asphalt production facilities that inject small amounts of water into the hot asphalt creating a volume expansion referred to as foaming, increasing the film thickness and compactability of the mix.

- Material based processes that release water into the mix with addition of heating creating a similar volume expansion as a free water system. This can come in the form of highly controlled aggregates or zeolites.

- Chemical or Organic additives that lower the viscosity of the Asphalt Binder in the production and compaction temperatures.

- Chemical surfactants that work to reduce the surface tension of the liquid asphalt at production and mixing temperatures, which improves mixing and compaction at lower temperatures, but does not affect the properties of the liquid asphalt.

Hypertherm™ is chemical additive that falls into the surfactant category. Hypertherm™ has shown to be able to reduce the production temperatures in the range of 110-120°C, and successfully compact mixes at temperatures as low as 80°C. The technology has been used in a number of projects across Canada and the United States and has been the topic of presentations at the Transportation Association of Canada and Canadian Technical Asphalt Association. [1,8,15]

1.2 Overview

WMA technology has grown to the point that the environmental and performance benefit of producing Asphalt Concrete at lower temperatures is widely documented. Environmental benefits include reduced fuel consumption and emissions, and enhanced working conditions for employees. Increased workability and compaction, improved constructability of joints, late season and cold-weather paving, as well as extremely long haul distances have all been documented successes for the technology. [8]

As the acceptance and implementation of WMA technology progresses and the number of technologies continue to grow, it becomes the application of these technologies that begins to significantly affect the industry. Warm Mix Asphalt and Hot Mix Asphalt recycling have complimentary attributes. Practical experience has found that the sometimes common issues with implementing WMA part-time like baghouse temperature, offsets the common high temperature with producing high rap mixes. The belief that producing WMA significantly reduces the initial aging of neat asphalt binders, should in theory help mitigate the accelerated stiffening of high RAP mixes due to the aging of the asphalt binder contributed by the RAP.

A successful application of these philosophies would produce a mixture that is easier and more sustainable to produce, and mixes and constructs more easily, while enabling both contractors and agencies to benefit greater economic and environmental savings of utilizing higher rap contents without the added expense and logistics of needing softer grade asphalt binders to maintain target binder rheology.

2. Project Details

One distinct advantage of WMA is that allows asphalt mixture production at significantly reduced temperatures. While the general understanding in industry is that oxidization and hardening of the asphalt binder are reduced at lower temperatures, the goal is to understand the effect on the asphalt binder grade, particularly when used in mixes that contain high RAP contents, which typically require higher production temperatures to successfully produce and construct. NBDOT specifications for High RAP Base (HRB) require 30% +/-5% RAP in the asphalt pavement mix design. PG verification and blending of the virgin and RAP binders are required at time of mix design using linear blending and lab testing to determine the initial binder grade. Designs typically require a virgin binder that is one or two grades softer than that required in new hot mix production (e.g. a reduction from PG 58-28 to PG 52-34 or PG 46-40).

A 1km trial section of WMA-HRB was constructed adjacent to a conventional HRB mix on Route 10 near Albright's Corner, outside of Fredericton, New Brunswick. The HRB (25mm with RAP) mixture design called for a PG reduction from 58-28 to PG 52-34. It was expected that the WMA additive would soften the binder sufficiently to permit the use of standard PG 58-28 asphalt cement. The resulting mix was produced at a temperature of 250˚F (120˚C) versus the HRB production temperature of 310˚F (155˚C). The asphalt plant utilized for asphalt concrete production was a 400tph Astec Double Barrel (2006) counter flow drum plant. The RAP milled from the surface course that was used on the project contained approximately 6.5% asphalt binder. The total asphalt binder content at time of production was 4.6%, with approximately 43% of this contribution coming from the RAP. The project also called for placement of a virgin NBDOT Type D (12.5 mm) surface mixture. For this project three large samples were taken of each mix to be used for analysis. All testing was completed on three individual samples and results reported as the average of the values.

The resulting testing matrix for evaluating the liquid asphalt properties was: 1. HRB with PG 52-34; 2. WMA-HRB with PG 58-28; and, 3. Type D with PG 58-28. Asphalt binder samples were extracted from field produced mixture for performance grade evaluation.

Mixture performance testing was conducted on as-produced HRB and WMA-HRB. Rut Resistance, Dynamic Modulus and Indirect tensile strength data was evaluated on specimens obtained from each mixture. These samples represent short-term aged mixtures as produced from a hot-mix plant. Resilient Modulus, Fatigue and Low temperature performance will be evaluated on additional samples and tested to predict the extended field performance of the pavements. Further testing will be conducted using various Non-Destructive Evaluation (NDE) methods to evaluate the in-place properties and structural response of the two pavement sections.

3. Mixture Properties

The mix design was performed in accordance with NBDOT Standard Specifications, and project special provisions. A summary of design and production properties are presented in Table 3.1

4. Asphalt Binder Rheology

Superpave binder classification of the theoretically combined extracted RAP binder and neat binder per the asphalt mixture design is necessary to verify the resultant PG grade of HMA mixture containing RAP. PG Grade classification includes simulated aging of the asphalt binder through plant production with the Rolling Thin Film Oven (RTFO) and long term aging in place with the Pressure Aging Vessel (PAV). In an attempt to predict the aging of asphalt binder with WMA production vs. conventional HMA, the temperature utilized in the RTFO was 120˚C vs. a conventional temperature of simulated aging of 161˚C. In this way we were able to compare the theoretical expected values for all three mixes (Type D PG 58-28, HRB with 30% RAP and PG 52-34, and WMA-HRB with 30% RAP and PG 58-28).

Three large (>1000kg samples) were taken of each mixture during the mix production in addition to the typical ERS samples and used to extract and fabricate all of the test samples. The asphalt binder was extracted from each sample and PG classification was performed without utilizing the RTFO as the mix was aged through the asphalt plant. The New Brunswick Department of Transportation Central Laboratory in Fredericton, NB performed the PG classification on the design and field produced mixtures. The resulting classification of the lab designed Asphalt Binder and the field recovered asphalt binder is presented in Table 3.1

The results of the asphalt binder characterization showed a number of interesting trends, the most significant of which is the relative extracted asphalt binder PG grade of the conventional HRB being significantly degraded from the mix design prediction while the extracted binder PG characterization of the HRB-WMA very nearly matched the design approximation. The data also verifies that the Asphalt Binder extracted from the Type D mixture verifies the traditional RTFO aging approximation of aging during asphalt concrete production to the virgin mixture design PG 58-28.

From this data one can tentatively draw the conclusion that the WMA technology performed as hypothesized by significantly improving the PG grade of the PG 58-28 with RAP to characteristics expected with a virgin binder grade bump to PG 52-34. The degradation of the traditional HRB mixture with the 52-34 asphalt binder leads one to believe that these softer binders added to superheated aggregates during production of high RAP mixes, are significantly more susceptible to oxidization and aging during production than traditional or stiffer asphalt binders at typical mixing temperatures, and may not be accurately predicted by traditional means.

5. *Mixture Performance Testing*

Performance testing of the as-produced pavements was conducted to quantify and compare the properties of the two mixtures. The experiment was conducted under the primary hypothesis that the two mixtures would perform similarly when analyzed with respect to rut and fatigue resistance, would show similar low temperature properties, and would have similar moduli. The secondary hypothesis is that the mechanics of WMA would show improved performance in some areas based on the concept that improved and more mixing and coating of the aggregates would give superior performance in tensile strength and fatigue.

5.1 Rutting Characteristics

Samples of both the WMA-HRB and conventional HRB were tested at Coco Asphalt Engineering, in Mississauga Ontario on the Asphalt Pavement Analyzer (APA) in accordance with AASHTO TP 63-7. The samples were compacted to approximately 7% air voids and tested at ambient temperature of 58°C, the design high-end binder grade. The results are provided in table 4.1.

Table 5.1 Rutting Characteristics of HRB mixes from NB Rte 10

Mix	**Air Voids**	**APA Rut Depth after 8000 cycles (mm)**	**STDEV**
HRB 52-34	7.19	3.085 mm	.35
WMA –HRB 58-28	7.14	3.364 mm	.38

Rut susceptibility of the two mixes was very similar, with the WMA-HRB showing slightly greater average rut depths. Both mixes meet the 8mm rut depth at 8000 wheel load cycles recommendation by the National Center for Asphalt Technology (NCAT) [10]

The higher rut depths shown appear to outline the WMA-HRB be the softer of the two materials supporting the data that the WMA-HRB mix produced have a softer high-end PG grading that the conventional HRB mixture.

5.2 Dynamic Modulus |E*| Testing

The adoption of Dynamic modulus to predict pavement performance in the Asphalt industry has been one of the primary innovations and topics of research and analysis over the last decade. Predictive models for estimating the dynamic modulus of pavement structures have been in use for some time, and are embedded in the hearts of most pavement design methodologies in use in North America. Recent advancement in technology has made the description of a pavement's dynamic modulus and its corresponding master curve much more mainstream. In addition to structural capacity, evaluating the dynamic modulus near the high temperature PG range relates well to the pavement's resistance to rutting, and analysis of the mid ranges of master curves, an acceptable measure of a pavements' resilience to forces in fatigue.

The Dynamic Modulus |E*| of the asphalt was conducted on specimens fabricated in accordance with AASHTO PP 60-09 by Stantec Ltd. Fredericton, NB, and testing conducted by Dr. Chris Barnes, with the center for Innovation and Infrastructure, Dalhousie University in accordance with AASHTO TP 62-1 and PP 62-1.

The specimens were prepared using a gyratory compactor to achieve a nominal air-void content of 4% in 150 mm diameter specimens for each mixture. These specimens were then cored to obtain 100 mm diameter specimens from the center of the larger gyratory specimens. These drilled specimens were then end cut at Dalhousie University to provide orthogonal surfaces in order to reduce bending effects during testing. Dynamic modulus tests were conducted on each specimen at frequencies of 25, 10, 5, 1, and 0.1 Hz at nominal temperatures of -16, 0, 10, 20 and 40°C in order to develop an average master curve for each mixture. The Dynamic modulus Data for all specimens is presented in Tables 4.2.1 and 4.2.2, an average master curve was constructed for each mixture, based on the average of each parameter obtained from all specimens shown in Figure 4.2.3

In order to compare these curves in a more practical sense, Figure 4.2.4 shows the variation in the average 10 Hz dynamic modulus versus temperature for the WMA-HRB and HRB mixtures. These curves appeared to be similar, except that the 'W' mixture exhibited a significantly (>10%) higher dynamic modulus compared to the 'H' mixture at temperatures below -10 °C.

The Average Dynamic moduli for both the WMA/HRB specimens and the traditional HRB specimens are essentially overlain on one another above the 0°C. The WMA-HRB shows slightly lower values through the mid temperature ranges, indicating equivalent or better predicted performance resisting fatigue, and slightly higher value in the high temperature ranges, showing equivalent or improve predicted resistance to rutting.

Commonly in industry, it is thought that dynamic modulus values obtained below 0°C are not easily correlated to any performance measure, verified in industry to the move to performing AASHTO PP61, utilizing the Asphalt Mixture Performance Tester, a test method which limits the temperature of specimens to 4°C on the low temperature end.

5.3 Tensile Strength

Conditioned and dry tensile strengths were completed on the comparative plant produced laboratory samples for the HRB and WMA-HRB in accordance to AASHTO T-283. A summary of results is included in Table 4.3 below.

Table 4.3 Summary of Tensile Strengths and Tensile Strength Ratios.

Mix	Dry Tensile Strength kPa	Wet tensile Strength kPa	Tensile Strength Ratio (%)
HRB 52-34	1003	815	81.3
WMA–HRB 58-28	1226	1011	82.4

The data clearly shows that utilizing WMA technology does not detrimentally affect the Tensile Strength Ratio (TSR) of the mixtures as commonly feared in industry. A further look shows that the Tensile Strength of the mixtures improved by over 20% compared to the conventional mixture lending support to the belief that improved coating and mixing caused by employing WMA technology improves uniformity and mitigates micro-fracturing effectively increasing resistance to failure under load.

6. Findings and Conclusions

With respect to our initial hypothesis, that utilization of WMA technology with RAP will result in improved the asphalt binder properties and performance, we can conclude specifically that:

- Binder rheology prediction models for RAP may not in all cases provide an accurate accommodation for superheating of aggregates during production of high RAP mixtures.
- It is possible to predict with significant confidence the final resultant grade of a WMA mixture using reduced RTFO temperatures.
- In this case study, it appears that the utilization of WMA technology and corresponding 60°F (35°C) temperature drop, effectively improved the low end PG grade of the extracted as-produced asphalt binder significantly.
- Dynamic Modulus, Rut Testing and Indirect Tensile Strength analysis appear to validate at least equivalent performance of WMA-HRB mixtures to conventional methods without the need for conventional grade bumping.

Further study of mixture performance tests of both laboratory fabricated specimens and samples cored from in situ production will draw clearer and more concise relationships and conclusions.

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Tables and Figures

Table 3.1 Mix Design Properties

Mixture Combined Blend		
Sieve Size	Percent Passing	NBDOT HRB Specification
25mm	100	100
19mm	96.7	84-98
16.0 mm	90.8	72-94
12.5mm	80.6	60-87
9.5mm	69.1	51-75
6.3mm	52.5	41-66
4.75mm	44.7	34-60
2.36mm	30.2	22-50
1.18mm	21.2	12-42
600um	16	6-32
300um	10.4	3-20
150um	6.1	2-8
75um	4.5	2-6.5
AC %	4.4	-

Volumetric Properties		
Property	Value	NBDOT HRB Specification
MRTD	2.648	-
BRD	2.553	-
Air Voids	3.6	3.5-4.5
VMA %	14.5	>13.5
VFA %	75	65-75
Film Thickness	9.9	>7
EFF AC	4.34	-
Absorbed AC	0.1	-
Superpave Properties		
Nini (8)	86.5	-
Ndes (100)	96	-
Nmax (160)	97.8	-
Dust/AC	1	-

Table 4.1 Classification of design and plant produced Asphalt Binder from NB Rte 10

Test	Kildair PG 58-28	Kildair PG 52-34 (56.8%) / Rec. AC (43.2%)	Kildair PG 58-28 (56.8%) / Rec. AC (43.2%) with Hypertherm	Type D Extracted Binder	HRB Extracted Binder	WMA-HRB Extracted Binder
DSR Results in kPa	Specification for Original Binder - 1.0 kPa min.					
DSR Result for Original Binder @ 58°C	1.43					
DSR Result for Original Binder @ 64°C	0.67	1.24	1.79			
DSR Result for Original Binder @ 70°C		0.598	0.877			
	Specification for RTFO Residue - 2.2 kPa min.					
DSR Result for RTFO Residue @ 58°C	3.71			3.12		6.69
DSR Result for RTFO Residue @ 64°C	1.63	3.18	2.60	1.50	11.40	3.10
DSR Result for RTFO Residue @ 70°C		1.49	1.18		5.55	1.49
DSR Result for RTFO Residue @ 76°C					2.67	
	Specification for PAV Residue - 5000 kPa max.					
DSR Result for PAV Residue @ 25°C					3460	2980
DSR Result for PAV Residue @ 22°C		2600	3280		4730	4340
DSR Result for PAV Residue @ 19°C	3920	3710	4820	3170		6200
DSR Result for PAV Residue @ 16°C	5740	5170	6890	4590		
DSR Result for PAV Residue @ 13°C				6410		
Stiffness Results in MPa	Specification for Stiffness - 300 MPa max. / m-value - 0.300 min.					
BBR @ -12°C - Stiffness					144	153
BBR @ -12°C - m-value					0.307	0.342
BBR @ -18°C - Stiffness	209	180	250	180	267	323
BBR @ -18°C - m-value	0.337	0.320	0.325	0.334	0.274	0.293
BBR @ -24°C - Stiffness	455	360	534	385		
BBR @ -24°C - m-value	0.277	0.279	0.266	0.285		
Actual PG Grade	61-30	66-31	66-29	61-31	78-23	67-27

Table 4.2.1 WMA-HRB Dynamic Modulus by Temperature

Specimen	Temperature	Frequency				
	(Celsius)	25 Hz	10 Hz	5 Hz	1 Hz	0.1 Hz
W1-5	-20	29669	29091	27857	23501	21046
	0	19684	17329	16260	12831	9440
	10	13571	11825	10518	8168	4976
	20	8064	6651	5700	3820	1911
	40	2404	1688	1277	679	393
W2-5	-20	24199	22891	21628	19990	15324
	0	19261	19194	18273	15478	11805
	10	13677	12331	11347	8843	5702
	20	9379	8013	6974	5001	2726
	40	3460	2552	2025	1076	550
W3-5	-15.9	30357	30549	29051	24537	22468
	0	19258	18904	17741	14708	10573
	10	14660	12615	11204	8076	5009
	20	8626	7054	6000	3921	1911
	40	2062	1405	1041	525	310

Table 4.2.2 HRB Dynamic Modulus by Temperature

Specimen	Temperature	Frequency				
	(Celsius)	25 Hz	10 Hz	5 Hz	1 Hz	0.1 Hz
H1-5	-15.9	25829	23463	21854	19350	13985
	0	19400	17277	16203	14460	10256
	10	13505	12113	11034	8157	5405
	20	10356	8690	7717	4857	2794
	40	3542	2673	2161	1216	703
H2-5	-15.9	29794	27128	25909	22425	17381
	0	20609	19963	18817	14020	11817
	10	14335	13205	12067	9764	6229
	20	9107	7624	6538	4514	2488
	40	3489	2570	2070	1178	674
H3-5	-15.9	22924	22574	21342	19471	14501
	0	16893	17695	17057	14671	10923
	10	13420	11492	10570	8069	5152
	20	7216	6152	5217	3567	1931
	40	3760	2256	1884	957	513

Figure 4.2.3 Average Master Curves for WMA-HRB (W) and HRB (H) mixes

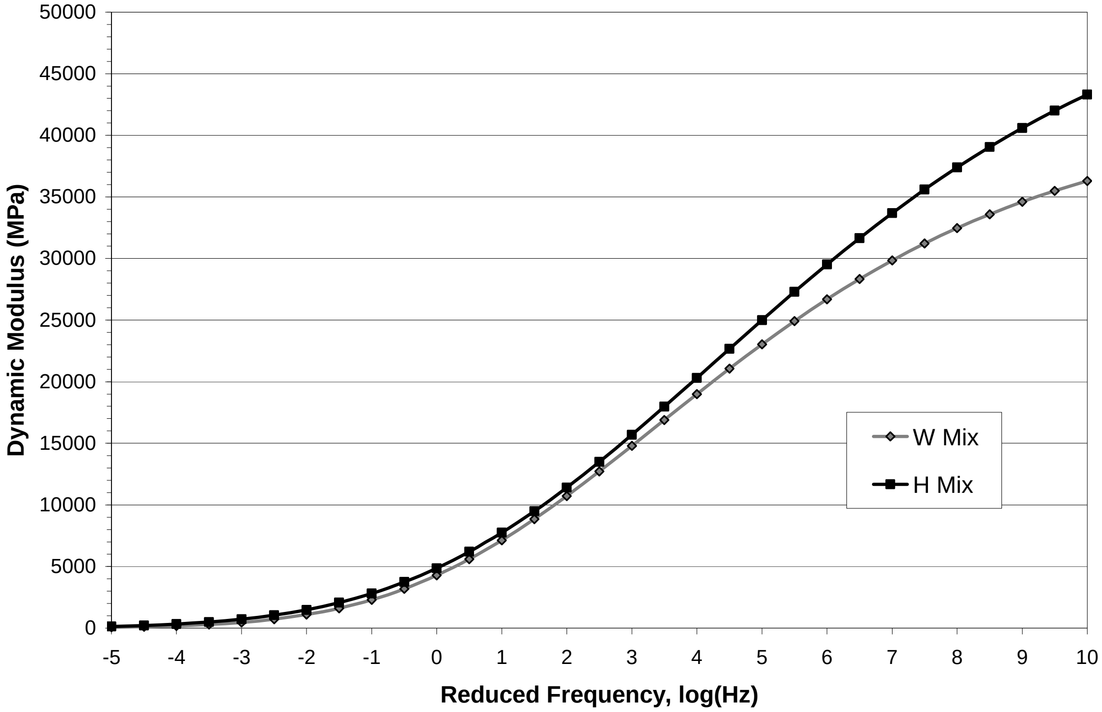

Figure 4.2.4 10 Hz Dynamic Modulus (MPa) vs. Temperature (Celsius)