Evaluating the Quality of Asphalt Binders and Plant Produced Asphalt Mixes through Recovered Asphalt Testing and other Mix Properties

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Abstract

Paving-grade asphalt binders are specified based on their properties in an original state following a specification such as the Performance Graded (PG) Asphalt Binder Specification. However, there has always been an interest in determining the properties of asphalt binder of in-place asphalt mixtures for research or forensic investigation purposes. With the increased use of reclaimed asphalt pavement (RAP), many user agencies are also looking for ways to evaluate the properties of the blended asphalt binder (i.e., new binder and old binder from RAP) since this also has an impact on the asphalt pavement performance.

One option is to conduct mixture performance testing. Another option is to conduct solvent extraction-recovery testing on the asphalt mixture and determine the physical properties of the recovered asphalt binder.

This research compares the physical properties of original asphalt binder, that binder extracted and recovered from a plant produced asphalt mix, and the properties of the asphalt mix as determined through performance testing. The purpose to evaluate how the various asphalt binder and mix parameters predict the performance of the asphalt pavement layer.

Seven asphalt mixes are included in the study using typical PG grades and surface asphalt mixes used in Canada. Two of the asphalt mixes incorporated 15% RAP for comparison with non-RAP mixes. Performance tests conducted on the asphalt mixtures include dynamic modulus, flow number, and Illinois Flexibility index (I-FIT), which is a performance index used predict the asphalt mixture's resistance to cracking obtained from a semi-circular bending (SCB) fracture test.

Introduction

In Canada, asphalt binder properties are accepted in accordance with the American Association of State and Highway Transportation Officials (AASHTO) standards: AASHTO M 320 – Standard Specification for Performance-Graded Asphalt Binder, with some agencies at various stages of adopting AASHTO M 332 – Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery Test. For asphalt mixes, the material is accepted based on criteria set on parameters for aggregates, asphalt binder, recycled materials, and volumetric properties such as air voids, voids in mineral aggregate, and voids filled with asphalt. The parameters are set because they have historically provided a good indication of a mixture's probable performance. (AI, 2014)

With the increased use of recycled materials such as reclaimed asphalt pavement (RAP) in asphalt mixes, many user agencies in Canada are looking for ways to evaluate the properties of the resultant asphalt mix, and the properties of the blended asphalt (i.e., new asphalt binder and old asphalt from RAP), since this has an impact on the asphalt pavement performance.

An option often selected by owners to evaluate the blended asphalt, is to conduct solvent extraction-recovery testing on the asphalt and determine the physical properties of the recovered asphalt in accordance with a standard specification. Users often use the same specification by which the asphalt was originally verified. However, there are concerns with the appropriateness of acceptance criteria based on recovered asphalt, since research has shown that the extraction and recovery process can impact the recovered asphalt properties because of contamination from the solvent and/or aggregate fines that affect the recovered asphalt viscosity.

The Ministry of Transportation Ontario (MTO) conducted proficiency testing in 2016 with five labs testing identical mix samples, where the results showed that testing variability was generally higher for recovered asphalt compared to original asphalt. (MTO 2016) Nonetheless, there is an increasing number of public sector agencies adopting recovered asphalt specifications for acceptance. The variability in test results also makes it more challenging to accurately predict pavement performance.

There is a need for industry to understand how the physical properties of original asphalt compare or relate to the properties of the same asphalt recovered from a plant produced mix, and to understand the impact of comparing values of recovered asphalt cement to test criteria and tolerances derived for unrecovered (original) asphalt binder. There is a need to understand the impact on the test results when the asphalt is polymer modified, and the impact when the asphalt mixes contain RAP.

Objective

The overall objective of this research is to evaluate the test methods being introduced into asphalt specifications and how they correlate with field verified test methods and parameters linked to pavement performance.

Methodology

A research plan was developed to evaluate asphalt binder properties through the life of the asphalt binder from asphalt binder supplier to asphalt mix production to placement, to see which parameters determined in the lab testing, are effective in relating to performance of the asphalt pavement layer.

This required sampling asphalt binder and asphalt mix at various stages of production and placement as illustrated in Figure 1:

Sample ‘A’ is asphalt binder sampled from the supplier’s terminal. This serves as the starting point of the asphalt binder’s “life” as it relates to this research.

Sample ‘B’ is the same asphalt binder (i.e., from the same batch/lot number) delivered to the asphalt mix production plant. This sample is obtained from the asphalt binder storage tank. Sample A is stored as back up, if there is suspicion of contamination of Sample B during transport from the supplier’s terminal to the asphalt mix production plant. Furthermore, current Ontario standards require original asphalt binder samples be obtained from the asphalt tank at the asphalt mix production facility.

Sample ‘C’ is plant produced asphalt mix, produced mix with the same asphalt from Sample ‘B’. This is collected for conducting performance testing to characterize the asphalt mix.

Sample ‘D’ is the same plant produced asphalt mix from Sample ‘C’ collected from the paving site.

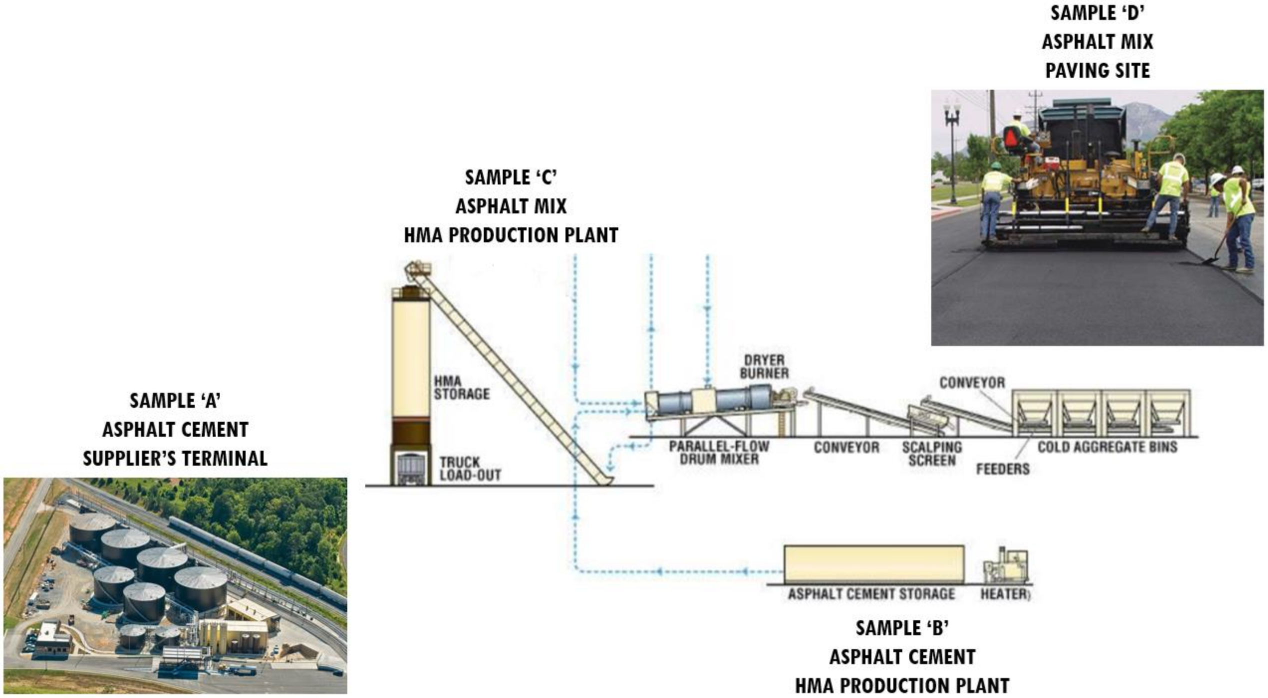

Figure 1: Visual representation of asphalt cement and mix sampling locations

Invitations were sent to members of the Ontario Road Builders Association (ORBA) to request material for the research. Materials collected are shown in Table 1:

Table 1: List of asphalt binder and asphalt mix included for the research.

Identification	Asphalt Mix Class	PGAC Grade	RAP Content
1-0708	HL1 / 12.5FC2	70-28	0
2-0809	12.5FC2	70-28	15
3-0915	12.5	58-34	15
4-1003	12.5	58-34	0
6-1006	12.5	58-28	0
7-1010	12.5FC2	64-28	0
8-1031	12.5FC1	58-34	0

The PGAC Grades collected cover the most common PGAC Grades in Ontario. The PG 70-28 for samples 1-0708 and 2-0809 were donated by the same asphalt binder supplier, and the respective asphalt mixes were produced at the same asphalt mix production facility. Both asphalt mixes contained the same aggregates, with the substitution of 15% RAP in 2-0809. The intent is to compare the properties of virgin asphalt mix and 15% RAP asphalt mix. The same applies to PG 58-34 liquid asphalt binder used in 3-0915 and 4-1003.

The tests conducted on asphalt binders and plant produced asphalt mixes are as follows:

Ash content (MTO 2015)

This test is used to determine the percentage of inorganic materials present in an asphalt or emulsified asphalt residue. The sample is burned away in a crucible and when it is returned to room temperature, it is weighed to compare with the starting weight. Ash content test evaluates the total inorganic content and cannot identify individual percentages of different inorganic materials.

PGAC Continuous or true grading (AASHTO 2012)

This test method is used to determine or verify the performance grade of an asphalt binder. Generally, PG is reported by two numbers, which are the average seven-day maximum pavement temperature (℃) and the minimum pavement design temperature (℃) that are expected to be experienced. For example, a reported value of PG 58-22 represents that this asphalt binder can be used where the average seven-day maximum pavement temperature is 58℃ and the expected minimum pavement temperature is -22℃ for the best expected performance being achieved.

Multiple Stress Creep Recovery (MSCR) Test (AASHTO 2014)

MSCR test monitors the creep and recovery conditions of the asphalt binder to see the tendency of permanent deformation. The test in performed with the dynamic shear rheometer on an RTFO-aged sample. The test temperature applied for the MSCR test if decided based on the actual environmental high temperature. Two parameters will be considered from the MSCR test, the nonrecoverable creep compliance (J_{nr}) and the MSCR percentage of recovery (MSCR). The J_{nr} parameter has been shown to correlate well with rutting in the field.

Double Edge Notch Tension (DENT) Test (MTO 2007)

The specimen is prepared with a 30-degree notch on each side, placed in a ductility bath then a pulling force is applied to each side as illustrated in Figure 2, then removed, to determine the load-displacement to recovery curve.

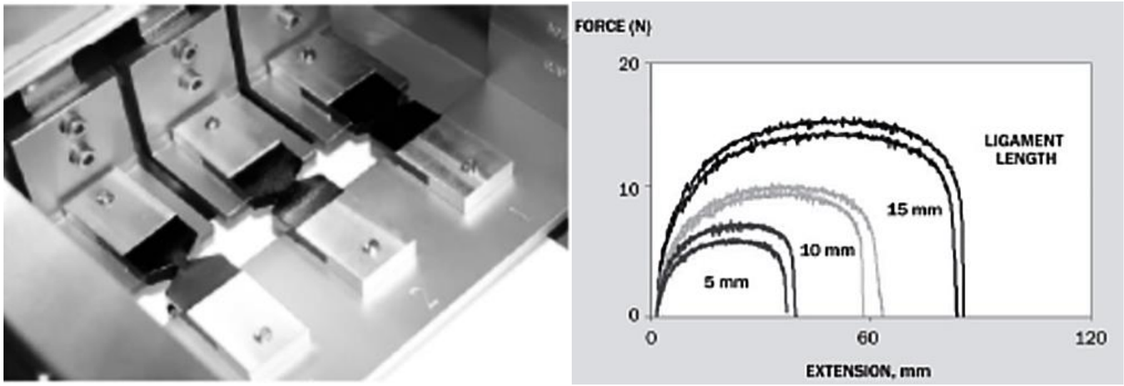

Figure 2: DENT test machine (left) and the typical data distribution (right)

Extended Bending Beam Rheometer (ExBBR) Test (MTO 2011)

The MTO introduced the Extended Bending Beam Rheometer Test (EBBR) to evaluate the physical hardening of the asphalt binder. Physical hardening of the asphalt binder is a phenomenon that occurs in when cooling the asphalt binder. The molecular movements and vibration decreases, which results in the reduction of the volume of the binder. It has been found that the extent of volume reduction is proportional to the temperature drop. In this test, the specimens are prepared and conditioned for 1, 24, and 72 hours at the environment of 10 and 20 degrees higher than the minimum design pavement temperature. Then, these specimens are tested under the condition of 16 ℃ and 20 ℃ higher than the minimum design pavement temperature. The material properties determined from the ExBBR test are low temperature limiting grades (LLTG) and the grade loss.

Delta Tc

The oxidative behavior of asphalt is one of the critical factors contributing to the performance of asphalt pavements. Pavement distresses associated with oxidized or aged asphalt binders are commonly referred to as non-load related distresses: block cracking, raveling, and longitudinal or transverse cracking.

Block cracking is a series of large (typically one foot or more), rectangular cracks on asphalt pavement surface as illustrated in Figure 3. It is caused by shrinkage of the pavement due to temperature cycles and is usually an indication that the asphalt binder has aged or oxidized significantly.

Figure 3: Block cracking in asphalt pavement

Raveling is wearing of the pavement surface caused by aggregate particles dislodging due to loss of asphalt binder. This type of pavement distress is usually an indication that the asphalt binder has oxidized and hardened significantly. Longitudinal and transverse cracks are cracks that respectively run parallel or perpendicular to the centerline of the pavement. They can be the result of poor construction or can be reflected from cracks in base layers. These cracks can also be the result of shrinkage in the asphalt pavement due to low temperatures or hardening of the asphalt binder. Overall, the main impact on non-load related distresses in asphalt pavements is the oxidation of the asphalt binder.

As researchers in the asphalt binder technical community and user agencies continue seeking physical property parameters that will improve hot mix asphalt pavement performance, are constantly investigating cracking index parameters to evaluate the cracking potential of asphalt binders. The idea being that if we identify parameters that can correlate with asphalt flexibility, we can use them to monitor when flexibility reaches a state where corrective action is needed before cracking occurs. One such parameter is ΔT_c.

ΔT_c was developed by Mike Anderson in 2011 as part of a research project involving airfield asphalt pavements, to evaluate the relationship between asphalt binder properties and non-load related cracking. The study relied on past research that showed some relationship between ductility (related to flexibility) and the durability of an asphalt pavement. (Blankenship et al. 2010)Ductility is an asphalt binder's ability to be stretched without breaking. ΔT_c is calculated using values from the Bending Beam Rheometer (BBR) test by subtracting the BBR m-critical temperature from the BBR stiffness-critical temperature:

$$\Delta T_c = (T_{s\text{-critical}} - T_{m\text{-critical}})$$

The critical temperatures, $T_{s\text{-critical}}$ and $T_{m\text{-critical}}$, are the temperatures at which the stiffness and m-value specification requirements are met (i.e., S=300 MPa, m-value=0.300) respectively. They can be determined following ASTM D7643, Standard Practice for Determining the Continuous Grades for PG

Graded Asphalt Binders; or AASHTO R29, Standard Practice for Grading or Verifying the Performance Grade (PG) of an Asphalt Binder which is already included in specifications.

In the BBR test, a constant load is applied to an asphalt beam, which is held at a constant temperature. The test temperature is related to a pavement's lowest service temperature. The purpose is to determine how the asphalt beam responds to mechanical stresses at low temperatures. This is important for asphalt pavements because as the surrounding temperatures drop, the pavement contracts (or shrinks), but the asphalt binder contracts to a much larger degree than the aggregates in the pavement. When these stresses exceed the tensile strength of the asphalt mix, a low-temperature crack develops in the pavement.

The Superpave Performance Graded (PG) system sets a criterion for creep stiffness (S) to minimize the contribution of the asphalt binder to low-temperature cracking: $S \leq 300$ MPa after 60 seconds of loading at the appropriate temperature.

The m-value is the rate at which the asphalt binder stiffness changes over time. A higher m-value is an indication that the stiffness may not increase as quickly when temperature decreases. This means the tensile stresses in the asphalt will be smaller as the contraction occurs, reducing the chances of low-temperature cracking. Therefore, the PG system specifies a minimum m-value of 0.300 after 60 seconds of loading at the appropriate temperature. Asphalt binders that are not too stiff at low temperatures and are able to relax built up stresses are desirable.

ΔT_c is intended to provide an indication of loss of ductility: when the asphalt binder cannot relax the stresses fast enough to prevent breaking. As asphalt binders oxidize and age, their ability to relax stresses at low temperatures diminishes. This would be captured in the BBR m-value and result in a higher (less negative) $T_{m\text{-critical}}$.

The ΔT_c of an aged binder would be more negative, than that of an unaged binder, and would be more likely to exhibit the pavement distresses described earlier: block cracking, raveling, and longitudinal or transverse cracking. This has generated a lot of interest in using ΔT_c to characterize asphalt mix containing (RAP), due to the contribution of highly oxidized asphalt from these recycled materials. ΔT_c can be measured from virgin asphalt and asphalt recovered from mix. (Blankenship et al. 2010)

Asphalt Mixture Performance Tester (AMPT) Flow Number

Most state highway agencies have implemented the Superpave volumetric mix design process created during the Strategic Highway Research Program (SHRP) as part of their system for designing asphalt mixtures. However, at the conclusion of SHRP no test was available that provided information on the probable performance of asphalt mixtures designed using Superpave volumetric mix design. The Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) sponsored research to develop and validate simple performance tests for permanent deformation and fatigue cracking to be incorporated in the volumetric mixture design process. The AMPT shown in Figure 4 was developed as part of this research. The AMPT was recommended to be used to conduct three tests to evaluate permanent deformation of asphalt mixtures: dynamic modulus (E*) using the triaxial dynamic modulus test, flow time (Ft) using the triaxial static creep test, and flow number (FN) using the triaxial repeated load test. The flow number has been correlated to the mixture's rutting resistance, with a higher flow number indicating higher resistance to rutting. (Witczak et al. 2002)

Figure 4: AMPT Equipment by Interlaken Technology Corporation

Illinois Flexibility Index Test (IFIT)

I-FIT test uses semi-circular bending (SCB) specimen geometry to determine the fracture resistance of an asphalt mixture at an intermediate temperature. The provisional standard test method, AASHTO TP-124, “Determining the Fracture Potential of Asphalt Mixtures Using the Semi-Circular Geometry at Intermediate Temperature,” calls for 50-mm thick, 150-mm diameter semi-circular specimens to be tested using a three-point bending principle, at the constant displacement rate of 50 mm/min. Figure 5 presents a photograph of the I-FIT test arrangement. A 15-mm deep, 1.5-mm wide notch is cut along the specimen’s axis of symmetry to force the failure location. Prior to testing, the test specimen is conditioned for two hours in an environmental chamber at 25°C, the standard test temperature.

Figure 5: I-FIT Test using Semi-Circular Bending (SCB) specimen geometry.

One of the primary outputs of I-FIT is the fracture energy, which represents the energy dissipated by the crack propagation. This parameter is calculated as the area under the load-displacement curve divided by the area of the crack that propagates during testing. The fracture energy is a function of both the strength and ductility of the material, which are related to the peak load and maximum displacement, respectively. Generally, the higher the fracture energy, the better the cracking resistance. However, it has been observed that mixtures that exhibit the opposite behavior may present similar fracture energy values. (Kaseer et al. 2018) For instance, in the I-FIT, a brittle material, usually manifested by a high peak load and low ductility, may have a similar fracture energy to a material with high ductility and a lower peak load. (Kaseer et al. 2018)

To differentiate between asphalt mixes, the post-peak characteristics of the load-displacement curve are used to assess the cracking resistance of asphalt mixtures more accurately. The Flexibility Index (FI), a resistance index, was developed based on calculations of the measured fracture energy and load-displacement curve slope at inflection point (m) values, as shown in Figure 6. Generally, higher FI value indicates the better premature cracking resistance of the asphalt mix.

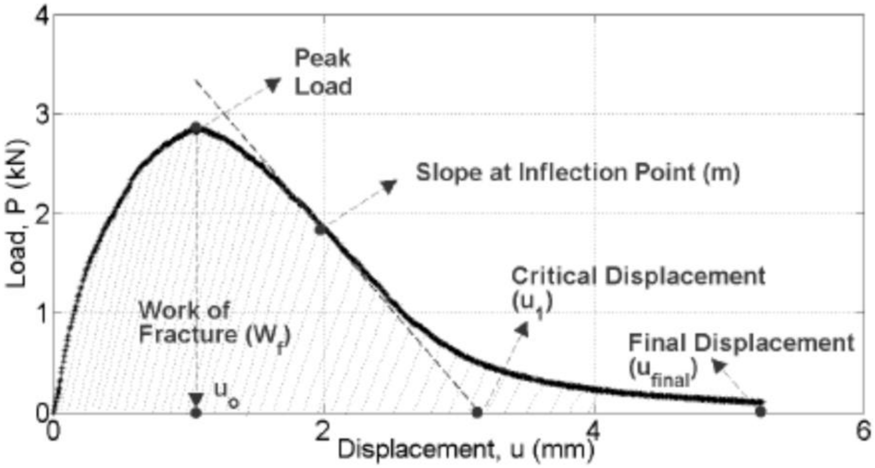

Figure 6: Example I-FIT load-displacement curve

Results and Discussion

Notes for all tables and figures in this section:

PG High = Performance Graded High Temperature
PG Low = Performance Graded Low Temperature
MSCR Jnr = Multiple Stress Creep Recovery Non-Recoverable Creep Compliance
LTLG = Low Temperature Limiting Grade
CTOD = Crack Tip Opening Displacement.
StDev = Standard Deviation
COV = Coefficient of Variance

The tank and recovered asphalt binder properties and summarized in Table 2 and Table 3.

Table 2: Tank Asphalt Binder Characteristics

PG	RAP	Mix ID	Ash	PG High	PG Low	MSCR Jnr	Grade Loss	LTLG	CTOD
58-34	0	8-1031	0.2	62.7	-36.9	0.91	1.5	-29.3	34.9
58-34	0	4-1003	0.6	62.5	-39.5	0.38	2.9	-36.8	30.4
58-34	15	3-0915	0.1	61.9	-36.7	0.52	3.3	-27.8	18.1
58-28	0	6-1006	0.1	58.9	-34.5	2.37	2.4	-30.5	14.9
64-28	0	7-1010	0.1	64.9	-35.5	0.19	3.1	-31.4	15.6
70-28	0	1-0708	0.1	72.4	-34.8	0.05	3.7	-30.5	13.2
70-28	15	2-0809	0.1	72.7	-35.3	0.05	3.4	-29.8	12.5

Table 3: Recovered Asphalt Binder Characteristics

PG Grade	RAP	Mix ID	Ash	PG High	PG Low	MSCR Jnr	Grade Loss	LTLG	CTOD
58-34	0	4-1003	1.1	66.9	-38.9	0.23	4.3	-30.4	11.9
58-34	15	3-0915	2.4	68.5	-34.5	0.57	4.6	-28.1	-0.1
58-28	0	6-1006	1.3	64.8	-34.1	1.26	5.4	-27.5	1.5
64-28	0	7-1010	1.7	69.9	-32.2	0.38	3.9	-25	4.9
70-28	0	1-0708	2.1	76.3	-35.2	0.04	4.8	-28.5	11.0
70-28	15	2-0809	2.8	78.5	-30.2	0.08	4.6	-23.2	3.5

In Table 3 the difference in ash contents between the tank asphalt and recovered asphalt binders suggest that the recovered asphalt have more aggregate fines present in the samples, which were not completely filtered during the extraction process. Aggregate fines in the recovered asphalt increases the asphalt stiffness, which will impact the measured properties. (Burr et al. 1990, 1991) If the recovered asphalt is contaminated with aggregate fines, and all other factors remain unchanged, this will produce higher PG high temperature, and produce higher or less negative PG low temperature and LTLG properties from the ExBBR test, as generally demonstrated in Table 3.

All factors were not equal however, because variables such as the quantity of aggregate fines left after extraction, possibility of residual solvent in the recovered asphalt, differences in lab aging of tank asphalt versus field aging through asphalt mix production, also have an impact on the recovered asphalt properties. (Wakefield et al. 2018; Wakefield and Tighe 2019) While aggregate fines in the recovered asphalt can increase stiffness, residual solvent can cause a negative hardening of the recovered asphalt binder. (McDaniel and Anderson 2001)

Delta Tc (ΔTc)

Table 4 and Table 5 show the calculated ΔTc values for the tank asphalt binders after 20 hours and 40 hours of PAV aging, respectively. The data shows ΔTc becoming worse (i.e., more negative) with extended aging, which supports the understanding of the impact of oxidation on the asphalt properties.

Table 4: ΔTc Values for 20- and 40**-hour PAV Aging**

Sample ID	58-34 8-1031	58-34 4-1003	58-34 3-0915	58-28 6-1006	64-28 7-1010	70-28 1-0708	70-28 2-0809
Average ΔT_c (°C)	0.9	0.8	1.3	1.5	0.9	0.7	0.8
StDev	0.6	0.5	0.5	1.1	0.4	0.7	2.6
COV	0.7	0.6	0.5	0.8	0.5	1.0	3.3

Table 5: ΔTc Values for 40-hour PAV Aging

Sample ID	58-34 8-1031	58-34 4-1003	58-34 3-0915	58-28 6-1006	64-28 7-1010	70-28 1-0708	70-28 2-0809
Average ΔT_c (°C)	-1.3	-2.7	-0.6	-1.1	-1.5	-2.2	-2.3
StDev	1.8	0.6	0.5	0.1	0.5	0.7	1.1
COV	-1.4	-0.2	-0.7	-0.1	-0.3	-0.3	-0.5

It is noted that the percentage of change in ΔTc between the 20 and 40 hours of PAV aging is not consistent for all the asphalt binder grades and therefore laboratory aging is a key component of any discussion pertaining to ΔTc. Figure 7 shows graphically the differences in ΔTc values with the two aging times.

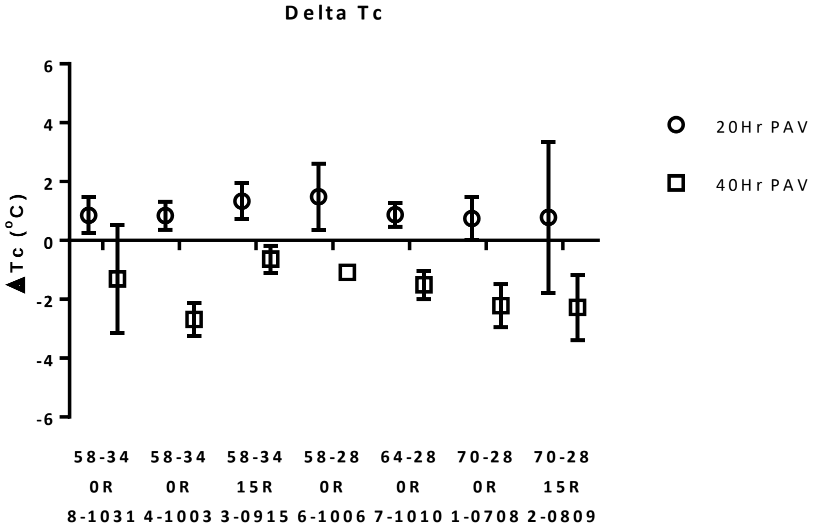

Figure 7: ΔTc Values of Ontario Asphalt Binders with 20- and 40-Hour PAV Aging

Table 6: AMPT Flow Number (Rutting) Characteristics

Sample ID	58-34 8-1031	58-34 4-1003	58-34 3-0915*	58-28 6-1006	64-28 7-1010	70-28 1-0708	70-28 2-0809*
Average Fn	68	28	109	78	136	2659	3119
StDev	41	6	46	18	11	1343	2336
COV	60	20	43	23	8	51	75

Illinois Flexibility Index (Cracking) Characteristics

Table 7: I-FIT Results for Plant Produced Asphalt Mixes

Sample ID	58-34 8-1031	58-34 4-1003	58-34 3-0915*	58-28 6-1006	64-28 7-1010	70-28 1-0708	70-28 2-0809*
Average FI	5.8	9.2	5.8	10.8	6.2	7.0	2.2
StDev	1.5	1.3	1.6	1.6	1.0	1.6	0.3
COV	25	14	27	15	16	22	14

Statistical Analysis

To evaluate how the properties of the asphalt binder and plant-produced asphalt mix correlate with performance, two correlation tables were produced to evaluate separately the properties of tank asphalt and recovered asphalt.

Table 8 is a correlation table that summarizes the material properties determined for the tank asphalt binder along with rutting and cracking properties determined from the AMPT and I-FIT respectively for plant produced asphalt mixes. Table 9 summarizes all the material properties determined for the recovered asphalt binder from plant produced mix, along with the rutting and cracking mix properties from the plant produced mixes.

For a correlation table:

- -1 indicates a perfect negative linear correlation between two variables.
- 0 indicates no linear correlation between two variables.
- 1 indicates a perfect positive linear correlation between two variables.

Understanding that not all the parameters have linear relationships, highlighted in the correlation tables are parameters that produce "strong" linear correlations (between |0.7 - 1|).

Highlighted in Table 8**Error! Reference source not found.** are the material properties determined for the tank asphalt and the rutting and cracking properties from plant produced asphalt mix that have a strong correlation. Observations made from Table 8 are as follows:

- Ash content (%) determined on tank asphalt has a negative correlation with the PG low temperature, i.e., as the ash content increases, the PG low temperature of the binders decreases (becoming less negative). Similar results are noted for the Low temperature limiting grade (LTLG) from the ExBBR test developed by MTO to address the physical hardening phenomenon that changes asphalt binder properties at low temperature.
- PG high temperature has a positive correlation with MSCR %Recovery and AMPT Flow number, i.e., for the samples in this research, the higher PG high-temperature grades correlate with better resistance to rutting captured by the AMPT Flow number.
- As RAP content increased (comparing 0% RAP with 15% RAP mix), the Flexibility Index decreased, suggesting the 15% RAP mix is more susceptible to cracking compared to the virgin asphalt mix.
- The Delta Tc values of the tank asphalt binders showed a positive correlation with the IFIT Flexibility Index of the resultant mix (i.e., the more positive the Delta Tc value of the tank asphalt, the larger the flexibility index, which means it would be more resistant to non-load related pavement distresses. The Delta Tc showed a negative correlation with AMPT FN, supporting our understanding that a less stiff asphalt mix that has a higher FI, would thus have a lower AMPT FN.

Highlighted in Table 9 are the material properties determined for the recovered asphalt and the rutting and cracking properties of plant produced asphalt mix that have a strong correlation. Comparing Table 8 to Table 9 show that less of the recovered asphalt properties correlated with the rutting and cracking performance tests that have been shown to correlate well with field performance.

Table 8: Correlation Table for Tank Asphalt and Plant Produced Mix Properties

TANK ASPHALT	*RAP*	*Ash*	*PG High*	*PG Low*	*MSCR Jnr*	*MSCR %Rec*	*Grade Loss*	*Grade Loss*	*LTLG (20Hr)*	*LTLG (40Hr)*	*CTOD*	*Delta Tc (20Hr)*	*Delta Tc (40Hr)*	*IFIT*	*IFIT Slope*	*AMPT Flow*
RAP																
Ash	-0.3															
PG High	0.3	-0.3														
PG Low	0.1	-0.9	0.3													
MSCR Jnr	-0.3	-0.1	-0.7	0.2												
MSCR %Rec 3.2kPa	0.3	0.1	0.8	-0.1	-1.0											
Grade Loss (20Hr)	0.4	-0.1	0.6	0.2	-0.6	0.7										
Grade Loss (40Hr)	0.2	-0.2	0.2	0.2	0.0	0.1	0.4									
LTLG (20Hr)	0.5	-0.9	0.1	0.6	0.1	-0.1	0.0	0.4								
LTLG (40Hr)	0.5	-0.8	0.1	0.5	0.0	-0.1	0.0	0.5	1.0							
CTOD	-0.4	0.7	-0.5	-0.8	0.1	-0.2	-0.7	-0.3	-0.4	-0.3						
Delta Tc (20Hr)	-0.4	0.4	-1.0	-0.4	0.8	-0.8	-0.6	-0.1	-0.2	-0.2	0.5					
Delta Tc (40Hr)	0.2	-0.4	-0.3	0.1	0.2	-0.4	-0.6	0.0	0.7	0.7	0.4	0.2				
IFIT	-0.7	0.4	-0.7	-0.2	0.7	-0.6	-0.3	0.1	-0.5	-0.4	0.2	0.8	-0.3			
IFIT Slope	-0.6	0.4	-0.6	-0.3	0.4	-0.4	-0.2	0.4	-0.3	-0.2	0.3	0.7	-0.1	0.8		
AMPT Flow	0.4	-0.3	0.9	0.4	-0.5	0.6	0.6	0.3	0.2	0.2	-0.6	-0.9	-0.3	-0.6	-0.6	

Table 9: Correlation Table for Recovered Asphalt and Plant Produced Mix Properties

RECOVERED ASPHALT	*RAP*	*Ash*	*PG High*	*PG Low*	*MSCR Jnr*	*MSCR %Rec 3.2kPa*	*Grade Loss (20Hr)*	*Grade Loss (40Hr)*	*LTLG (20Hr)*	*LTLG (40Hr)*	*CTOD*	*Delta Tc (20Hr)*	*Delta Tc (40Hr)*	*IFIT*	*IFIT Slope*	*AMPT Flow*
RAP																
Ash	0.2															
PG High	0.3	0.5														
PG Low	0.3	0.4	0.5													
MSCR Jnr	-0.3	-0.2	-0.7	0.0												
MSCR %Rec 3.2kPa	0.1	-0.2	0.5	-0.2	-0.8											
Grade Loss (20Hr)	0.1	0.7	0.5	0.3	-0.3	0.0										
Grade Loss (40Hr)	-0.3	0.4	0.1	0.0	-0.1	-0.1	0.3									
LTLG (20Hr)	0.4	0.5	0.5	0.8	-0.1	-0.2	0.4	0.2								
LTLG (40Hr)	0.1	0.7	0.5	0.6	-0.2	-0.1	0.6	0.5	0.8							
CTOD	-0.3	-0.6	-0.5	-0.6	0.1	0.2	-0.8	-0.3	-0.6	-0.6						
Delta Tc (20Hr)	-0.5	-0.5	-0.5	-0.8	0.2	0.1	-0.3	-0.1	-0.7	-0.6	0.5					
Delta Tc (40Hr)	0.1	-0.7	-0.5	-0.2	0.3	0.0	-0.6	-0.5	-0.4	-0.8	0.6	0.3				
IFIT	-0.7	-0.2	-0.6	-0.4	0.6	-0.5	0.0	0.0	-0.4	-0.2	0.1	0.5	0.0			
IFIT Slope	-0.6	-0.2	-0.6	-0.5	0.3	-0.3	0.0	0.1	-0.5	-0.2	0.2	0.6	0.0	0.8		
AMPT Flow	0.4	0.1	0.8	0.4	-0.5	0.6	0.2	-0.1	0.3	0.1	-0.2	-0.3	0.0	-0.6	-0.6	

Summary of Findings

Research has shown that the extraction-recovery procedures and solvents used can have an impact on the recovered asphalt physical properties. In this study the solvent used was controlled, using only reagent grade TCE. Nonetheless, other variables such as the effect of aggregate fines, the possibility of residual solvent from the recovery, the process of plant production, and the inclusion of RAP in some mixes are all still variables that can significantly impact the properties of the recovered asphalt.

The significant increase in ash content, in the recovered asphalt (up to 100% increase compared to tank asphalt) coupled with the difference in oxidation due to lab aging versus plant production, (Wakefield and Tighe 2019) produced rheological properties that show the recovered asphalt was stiffer and less representative of the tank asphalt, namely: the recovered asphalt had higher PG high temperatures, higher PG low temperatures, higher LTLG, higher Grade Loss, and lower CTOD results.

Additionally, the physical properties of recovered binder, have been shown to have much higher variability than would be experienced if performing the same physical property tests on tank asphalt. (MTO 2016; Wakefield et al. 2018)

Furthermore, new parameters and performance tests proposed in this research: the Delta Tc (ΔT_c) parameter for asphalt binder, the Illinois Flexibility Index Test (I-FIT), and Asphalt Mix Performance Tester (AMPT) Flow Number for the asphalt mixes, showed better correlation with other field verified performance criteria than with recovered asphalt binder properties.

If the testing protocols used for acceptance are not both accurate and precise, owners will have a challenge distinguishing between good and poor performing materials. As such, it is recommended that users should exercise caution when comparing values of recovered asphalt to test criteria and variability derived for unrecovered (original) asphalt.

Recommendations for Future Work

This research determined that there is a statistically significant difference in test results for tank and recovered asphalt for several parameters due to the increased fines in the recovered asphalt which produced an overall stiffer binder. During the time of this research, MTO was developing a new test procedure to refine the solvent extraction and recovery procedure to reduce the residual fines. It is recommended that any changes to test procedure to be followed with another industry analysis to determine the impact of the procedural changes on the test results.

The research also showed that there was no difference in test results when testing PG low temperature of tank and recovered asphalt, except for PGAC 64-28. This suggests that there is an opportunity to use the results from testing PG low temperature to calculate Delta Tc values for recovered asphalt from plant produced asphalt mix.

The I-FIT test for cracking resistance of asphalt mixtures showed that the asphalt mixes with 15% RAP had lower FI values than their equivalent virgin asphalt mixes, additional data can be collected going forward to determine the appropriate FI threshold to provide desirable premature fatigue cracking resistance.

Furthermore, pavement distress data in the field can be collected from in-service highways where the asphalt mixes investigated in this research were constructed. The test data obtained for Delta Tc, I-FIT Flexibility Index, and AMPT Flow Number in conjunction with the in-service pavement distress data can be used to fine-tune preliminary acceptance criteria for I-FIT and AMPT FN, to allow asphalt mixes to be eventually accepted based on asphalt mix performance testing.

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