FHWA Asphalt Binder ETG, REOB – Re-refined Engine Oil Bottoms Residue – Task Force

Report to the September 2015 FHWA Binder ETG
September 15, 2015

Introduction

Lubricating oils used by vehicle engines have to be replaced at least every 5000 to 10000 miles depending upon the type of vehicle being used. This oil used to be dumped, but now most of it is re-refined and reused. This is done in a multi-step process, in which items such as water, solids, lighter oils, dissolved metals, degraded additives, etc. are removed. The oil bottoms from this process – REOB have been used in the paving industry since the 1980s, typically at an addition rate of 3 to 10%.

In some areas concern has been expressed over the use of these materials. In some areas such as New England these have been banned from used and in certain areas of Canada they have been suspected by various researchers as contributing to cracking propensity of binders. However, much of the work conducted to date is of a very limited nature and concerns exist with regard to the validity of the research and how this impacts the industry.

As a consequence of the industry and agency concerns several initiatives have been started to address this issue. The Asphalt Institute has from a task force (http://www.asphaltinstitute.org/re-refined-engine-oil-bottom-residue/) and the Asphalt Modifiers Association has published a news bulletin on this (http://modifiedasphalt.org/news-bulletin-reob/). In addition AASHTO also has a REOB task force.

During the April 2015 Binder ETG several presentations were made on REOB or related issues such as the characterization of cracking with recycled materials. As a consequence of this the ETG decided to form a task force with the initial objective of summarizing the presentations and providing further input and advice on the REOB issues. This document sets out the summary of those presentations. This document will be updated as developments take place.

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Presentations at April 2015 ETG Meeting

Seven presentations were given at the ETG. These are listed below and include a hyperlink to the downloadable version on the Asphalt Institute web site. A few comments is made on each of these papers has been made and the key findings summarized.

Item #	Authors	Title	Organization(s)
1	Louay N. Mohammad Sam Cooper, Jr. William H. Daly Ioan I Negulescu Sreelatha Balamurugan	Intermediate Temperature Fracture Properties of Asphalt Mixtures Containing RAS: Impact of Recycling Agents	LA Transportation Research Center Louisiana State University
2	Bill Ahearn	Why is there an AASHTO REOB Task Force?	VT Agency of Transportation
3	Bill Ahearn	Where's My Pavement Today?	VT Agency of Transportation
4	Mark Buncher	AI's REOB Task Force	Asphalt Institute
5	Gerald Reinke Andrew Hanz Doug Herlitzka Steve Engber Mary Ryan	Further Investigations into the Impact of REOB & Paraffinic Oils on the Performance of Bituminous Mixtures	Mathy Technology & Engineering
6	Walla Mogawer	Evaluating the Influence of Aging on the Chemical and Performance Characteristics of REOB Modified Asphalt Binders & Mixtures	UMass Dartmouth
7	Nelson Gibson	Recycled Engine Oil Bottoms as Asphalt Binder Additive	FHWA
8	Thomas Bennert	Asphalt Binder and Mixture Properties Produced with REOB Modified Asphalt Binders	Rutgers University

1. Intermediate Temperature Fracture Properties of Asphalt Mixtures Containing RAS: Impact of Recycling Agents

This paper presented data in a mixture fracture test and binder chemical analysis in order to and compared the performance of various types of recycling agents REOB materials. The intent was to look at various types of materials, including REOB, used as a potential recycling agent (RA). The target was to produce mixes with similar volumetrics (VMA and VFA) to a mixture containing no RAS. See Figure 1.

Physical performance was captured by the Semi Circular Bend (SCB) at intermediate temperature and Hamburg Wheel Tracking (HWT) tests. Chemical evaluation was conducted using Gel Permeation Chromatography (GPC) and Fourier Transform Infrared Spectroscopy (FTIR).

Key findings – RAs, including REOB, enhanced the extraction of the asphaltenes from the RAS. Associated asphaltenes were confirmed via GPS. The C=O from FTIR is not a reliable indicator of intermediate fracture. The use of RAs did not reduce the concentration of the highly associated asphaltenes or improve the fracture properties as evaluated by the SCB at 25^{o}C, see **Error! Reference source not found.**.

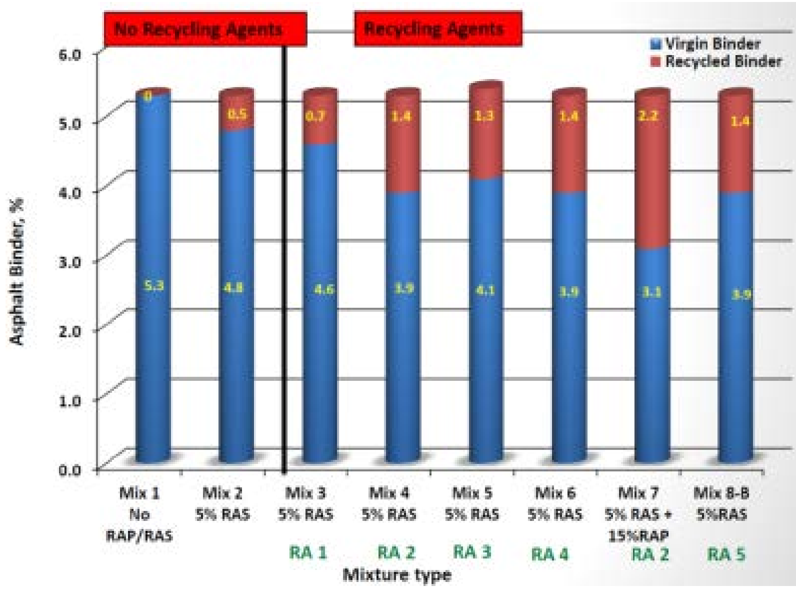

Figure 1: Range of mixes investigated by Mohamad et al.

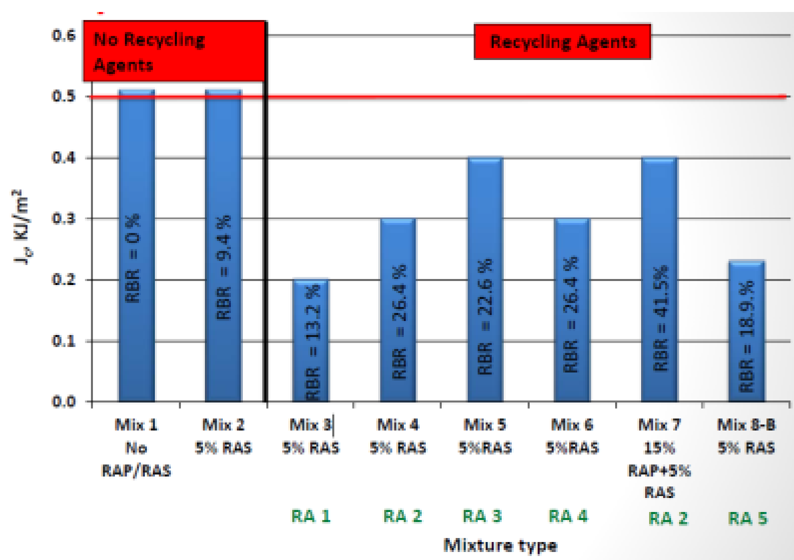

Figure 2: J_c computed from SCB test at 25^{o}C

2. Why is there an AASHTO REOB Task Force?

This presentation was given from a Vermont perspective and noted issues of unknown cause that have been documented in many states. Some statistics was presented that noted around 60% of states have seen in PG binder modified with REOB.

Most states assumed that PG Binders did not include other materials without disclosure based on the Standard Specification for Asphalt Binder AASHTO M-320. However, the wording in the standard notes "Asphalt shall be prepared by the refining of crude petroleum by suitable methods, with or without the addition of modifiers" (M-320 5.1) and "Modifiers may be any organic material of suitable manufacture that is used in virgin or recycled condition…" (M-320 5.2) which effectively allow the use of REOB. It was noted that 9 states prohibit; 1 state allows, 2 State / Province conditionally allow; 25 states have no REOB specific language.

A discussion was give on:

- Best practices for the identifying the presence and amounts of REOB in asphalt pavements
- Recommended additional research necessary to fully evaluate the allowance of REOB into asphalt pavement treatments, or mitigation of its use if necessary
- Preliminary risk assessment of member States' asphalt binder specification and associated recommendations
    - Field performance has been identified as a major concern for States with two specific issues – premature cracking and atypical raveling. The failures are not known to be exclusively caused by REOB based on current research.

Key findings – The ASSHTO Task Force will report on each element of the charge. The next steps will focuses on building robust data sets for decision making which will price/value ratios show small savings for large risk in asphalts. Performance not formulary is the direction of specification evolution, but current failure rate is not an option.

3. Where's My Pavement Today??

This presentation was given from a Vermont and other northern states perspective documented some of the issues that the state has seen with pavements. In particular, raveling, erosion and loss of mastic were highlighted in the various photographs (examples shown from VT, ME, MT, WI) shown during the presentation. One of these is shown as Figure 3.

Figure 3: Example of Loss of mastic, raveling (3yr, WI I90/94)

The presentation discussed the need to consider PG binders due to the changes in asphalt production and refinery processes. To address these issues the NCHRP project "The Impacts on Pavement Performance from Changes in Asphalt Production" will:

- Identify changes in crude oil refining related to asphalt binder production that have occurred since 1996.
- Investigate incidents of premature asphalt pavement failure occurring in several states and provinces since the mid-2000s. Identify the principal failure mechanisms.
- Evaluate the correlation between major changes in oil refining/energy market demands and occurrences of premature pavement failure.
- Compare the physical and chemical properties of current asphalt binders with binders from different periods, either through recovery from field samples or from stockpiled reference samples such as those collected by the Long Term Pavement Performance program.
- Identify gaps in the existing PG binder specification that may be leading to use of binders that contribute to early pavement failure.
- Evaluate binder tests to determine how they can be used to better predict actual pavement performance.

Key findings – While not necessarily focusing on REOB this presentation highlighted some concerns in pavement durability that has occurred in recent years. The new NCHRP project is considered to be very important in addressing these issues and deficiencies in the specifications.

4. AI's REOB Task Force

This presentation made on behalf of the Asphalt Institute supports the responsible modification of asphalt materials for improved performance and better life cycle costs, but does not endorse any specific or proprietary form of modification. An illustration supplied by Safety-Kleen identified REOB – also termed as VTAEs (Vacuum Tower Asphalt Extender). Information was presented on National Oil Recyclers Association (NORA) on VTAE (position paper dated 9/5/14). A draft specification including Flash Pint (COC), mass change (RTFOT) solubility and viscosity was presented. The viscosity at 140°F is specified as a maximum of 5000 cP. Two samples tested by MWV showed very different properties for viscosity and significantly less than the 5000 cP value.

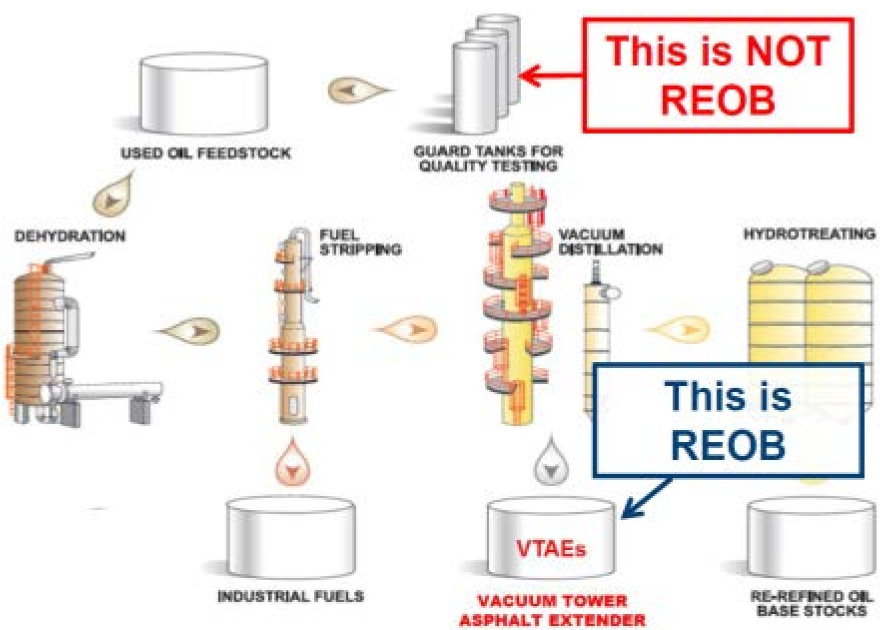

Figure 4: Identification of REOB in manufacturing process (supplied by Safety-Kleen)

The issue of conflicting results was raised and two examples given as shown below.

Point	Counter-Point
Bitumen containing Engine Oil Residues (EOR) exhibit • increased physical hardening • lower strain tolerance • high metals content Connected dots: thermal degradation products (from the oil and oil surfactants in the EOR) are oxidatively labile and the metals could act as oxidation catalysts	Bitumen containing Re-refined Heavy Vacuum Distillate Oil (RHVDO) did not exhibit • accelerated aging (at RHVDO levels up to 20%) • increased asphaltene content with extended PAV aging • (in a subsequent study) no increased stripping potential at RHVDO levels of 6%
Hesp, S. et.al., "X-Ray Fluorescence Detection…," Intl J. Pave. Engineering, 2010, 11, 541.	D'Angelo, J. et.al., "Asphalt Binder Modification…," Can.Tech. Asphalt Assoc., 2012, 57, 257.

The view was expressed that as we get wiser we can overcome these conflicting viewpoints. Guidelines and advice can be developed that considers various inputs.

Key findings – Information was presented on general finding to date, as follows:

- Used to soften PG grade (lowers both high and low end)
- Added benefit is that UTI can sometimes be increased
- Increase of RAP/RAS has led to softer grades being specified, which has led to increased demand for REOB or other fluxes.
- "Typical" dosages appear to be in the 4-8% range - although some have reported much higher
- Various REOB products may behave differently in asphalt (viscosities can be very different and different dosages needed for same grade drop)
- Interaction with base asphalt
- XRF can detect REOB, but cannot reliably quantify it (sample needs to be from tank versus extracted from roadway core - lots of confounders including tire rubber, oil drippings, extraction process.
- A concern by some is that REOB (and other paraffinic additives) may cause binder to become more m-controlled under aging

5. Further Investigations into the Impact of REOB & Paraffinic Oils on the Performance of Bituminous Mixtures

This presentation was a follow-up presentation to that made in September 2014. The presentation also contained data from bio derived oil, paraffinic base oil, binder from tear off shingles. Testing included evaluation of ΔTc, DENT, others, etc. It should be noted that the ΔTc in this study is calculated from 4mm DSR work and is (G(t) –m) with the exception of the data on slide 38 (BBR data from 20hr. PAV tests performed in 2000[1]).

The testing included 20 and 40 hour PAV and the ranking produced by both these methods appeared similar although the 40 hour data more closely matched the field condition. It should be noted that the CTOD from the DENT test did not capture the performance as well as the ΔTc method. It was noted that

[1] Some marginal difference could exist between the numbers derived from the different methods.

the ΔTc has no limiting value whereas the data shows a trend that the CTOD has a limiting value of around 4.

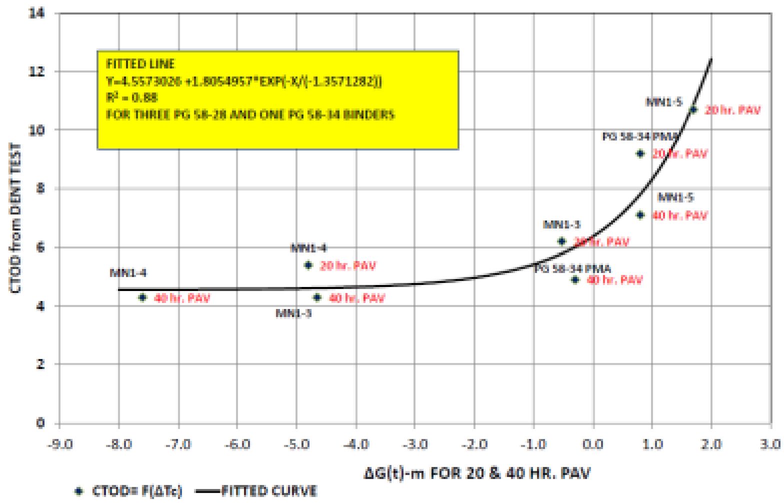

Figure 5: CTOD from DENT vs. ΔTc

The presentation showed data from various projects, some of which had cracked more early than expected. Sufficient data has been generated to show that paraffinic base oils have impact similar to REOB. Regardless of how modified the total distress appears to be well correlated to the ΔTc.

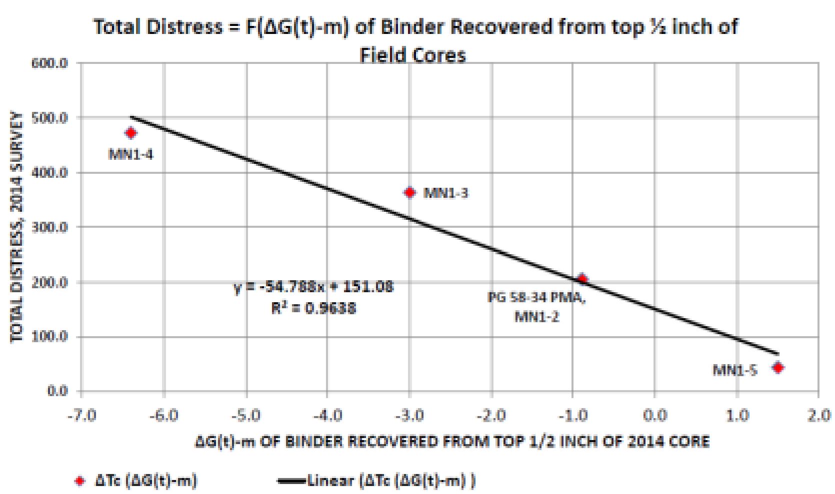

Figure 6: ΔTc from binder extracted from field cores versus total distress

Key findings – There are additives that can negatively impact mix performance because of their impact on the extent to which they accelerate the loss of m-value in the binder. Even without deleterious additives binders from different sources age at different rates. However with a test such as the ΔTc of the 40 hr. PAV we would at least know that this is a pavement to monitor for signs of deterioration. A judicious monitoring of the rate at which the ΔTc is degrading over time would be a good indicator of how closely we approaching the 40 hr. PAV result.

6. Evaluating the Influence of Aging on the Chemical and Performance Characteristics of REOB Modified Asphalt Binders & Mixtures

This presentation was focused on a study to be conducted by UMass Dartmouth on REOB materials to address 1) what is the minimum and maximum REOB dosage to reach the target low temperature grade (i.e. -28°C); 2) what is the effect of the maximum dosage on the properties of the asphalt binder after short and long-term aging; 3) what is the effect of the maximum dosage on the performance of asphalt mixtures both short and long-term; 4) do all REOB sources use the same dosage to reach the target low temperature grade; 5) are the REOB samples consistent amongst different samples of the same REOB product obtained from different lots; and 6) how does REOB compare to other products such as Hydrolene that have been used to modify base binders to meet the target low temperature grade. Data was presented that showed the effect of three materials (two REOB and Hydrolene H90T) on the binder grade. In addition several binders contained 1% PPA. The greater UTI's were all obtained with grades which contained PPA.

Key findings – Limited at this time to the binder grades as noted above.

7. Recycled Engine Oil Bottoms as Asphalt Binder Additive

This presentation contained some chemical and physical properties on REOB performance. The variation in REOB chemically from XRF-Spectrometer analysis is shown in Table 1. This clearly shows a large variation in chemical composition.

Table 1: Components from XRF analysis

Material	Amounts found
Phosphorous	1.5 - 1.9%
Sulfur	1.5 - 1.9%
Calcium	7,204 - 10,901ppm
Iron	372 - 1,838 ppm
Copper	704 - 1,563 ppm
Zinc	4,554 - 7,213 ppm
Molybdenum	288 - 669 ppm

For differencing percentages of REOB the grade temperatures are impacted. The DSR High Temp, BBR m-Value, BBR Stiffness grades all drop one grade for approximately 9, 21 and 9% REOB respectively. The scatter/variability appears to be significantly higher for the intermediate grade. Poor performance data from the ALF was suggested to be, after 5-years, anecdotally attributed to REOB.

Data was presented that considered the degree of hardening of the materials looking at the $G^*.\sin\delta$ parameter (at 10Hz and 19C). It was commented that the exploratory practices using 2 x PAV is a good step in the right direction. Other binder testing included DSR LAST (Linear Amplitude Sweep Test), ABCD fracture temperature, DENT strength and CTOD. Mixture testing included AASHTO T283, Hamburg WTT, fatigue testing and TSRST (strength and temperature).

Key findings – REOB can be readily detected but you cannot tell exactly how much is there. Some round robin XRF results may shed more light on this aspect. Effect of REOB depends on base binder since variation exists between REOB suppliers & their samples resulting in the same concentration sometimes producing different PG grades.

REOB softens and reduces tensile strength, binder notched tension (DENT), mix wet and dry IDT strength and is also reflected in TSRST results. REOB did not appear to interfere with the antistrip agent.

In 2 of 3 cases, REOB improved binder intermediate temperature parameters for fatigue / strain tolerance. Larger ΔTc (termed rheological disruption) was observed when REOB contents were higher and was made higher by extended aging. REOB also affected the moisture susceptibility data. Low concentrations of REOB did not appear to adversely affect binder and mixture properties but high concentration of REOB consistent with loss of strength in different binder and mix test methods. Further examination of m & S as "flag" (ΔTc) is warranted and the use of a minimum value for S should be reexamined.

8. Asphalt Binder and Mixture Properties Produced with REOB Modified Asphalt Binders

This presentation included data on 8 binders (2 REOB sources – 6 modified, 2 controls).

Asphalt Binder Testing included; PG grading (BBR 20 and 40 hour PAV aging), master curves (on original, RTFO, PAV 20 hr., PAV 40 hr.), Glover-Rowe Parameter, Rheological Properties, DENT test (PAV aged). Asphalt Mixture Testing (STOA & LTOA) consisted of; dynamic modulus, Flow Number, Overlay Tester, flexural beam fatigue, SCB (at intermediate temperature) and TSRST.

The binder results show clearly the change in ΔTc with higher percentages of REOB (see Figure 7). A strong relationship is also shown clearly evident for the rheological index (R) versus the cross over frequency (ω_c) - Figure 8. These two plots enable many of the other rheological parameters to be calculated such as the Glover-Rowe parameter.

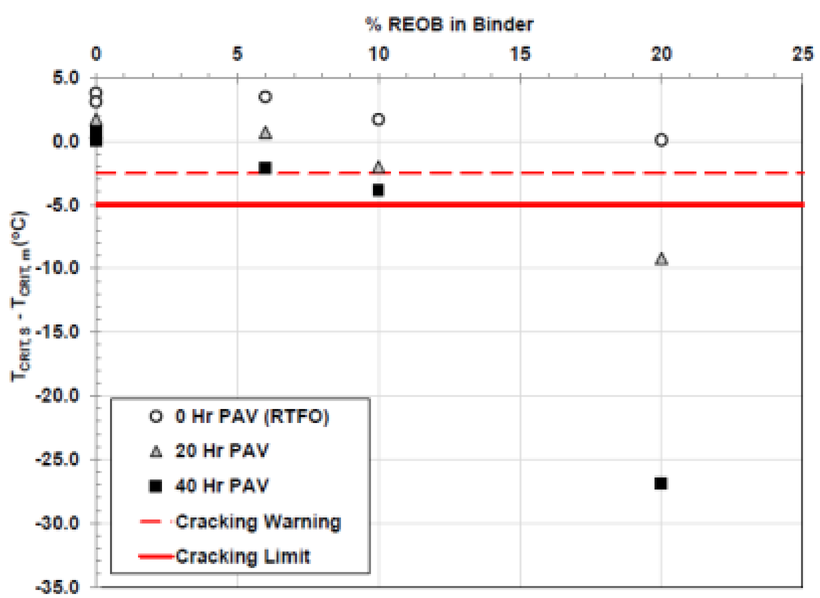

Figure 7: ΔTc versus % REOB

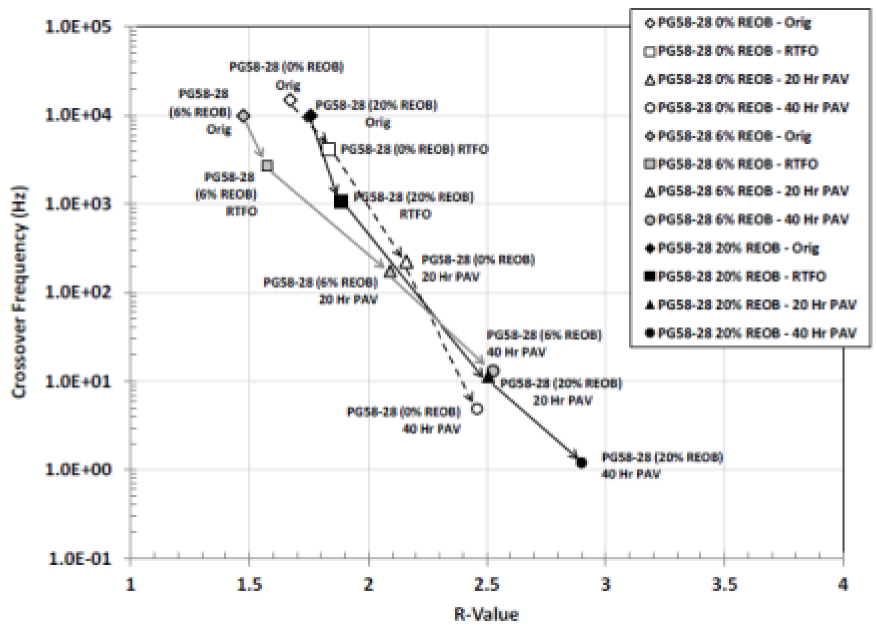

Figure 8: R value vs. Cross-over frequency

The mix test data – cracking performance was then compared to the binder data. The comparisons were only good between the Overlay Tester. The data comparing the overlay tester with the bending beam fatigue showed an inverse relationship – high low life in overlay tended to have a high life in bending beam fatigue. Various plots were produced showing binder parameters vs. the overlay test data. Those that produced good correlations were ΔTc (see Figure 9), DENT COD, G-R parameter, cross-over frequency.

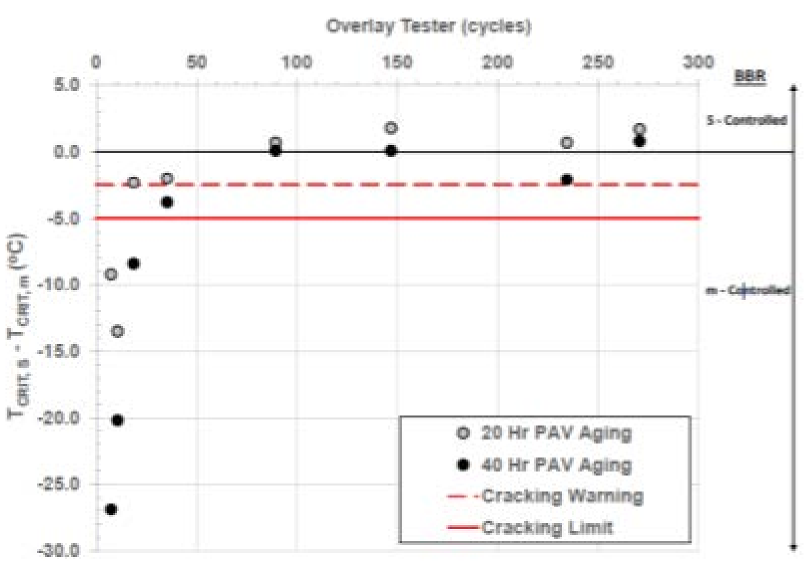

Figure 9: ΔTc versus overlay tester results

Key findings – Stiffness and aging behavior in mix dynamic modulus (E*) tests of REOB and neat binders gave similar results. A different ranking between fatigue cracking mixture tests existed (bending beam vs. overlay tester). Low temperature TSRST performance differed based on source of REOB and binder.

Binder "fatigue" tests correlated well with the Overlay Tester and were sensitive to REOB dosage (DTc, ω_c, G-R, DENT CTOD). Stiffness based tests do not show much difference between binders with and without REOB. REOB dosage rate has an impact on performance, but magnitude not the same for each REOB source.

Discussion

The presentations made contain some common themes and some differences between the results expressed. This discussion will give an overview of issues considered pertinent.

Rheology

Several rheological parameters have been presented that have strong correlations. These are the DTc parameter (from either 4mm rheology or BBR data), the Glover-Rowe (G-R) parameter, R (rheological index) and cross-over frequency.

All of these parameters can be interrelated from understanding the relationship between loading time (or frequency) and temperature. However, it should be noted that the G-R and the ΔTc capture the same characteristics whereas the R and ω_c capture different features of the master curve. R captures the shape and ω_c captures an equivalent stiffness/hardness of the binder. The ΔTc is an easy parameter to derive since it is effectively part of the data measured with standard PG binder evaluation. The G-R parameter could be interpreted from an existing PAV data set (BBR and DSR) but is anticipated to be more accurately defined by conducting a test at an alternate condition. The testing scheme could include single or multiple measurement points and while some testing has been conducted at 15^{o}C – this could easily be translated to another temperature and frequency using rules of time-temperature supposition.

Another way to consider the master curve is by considering the data in frequency or time domain. The time domain is typically used with BBR to assess the critical values of S(t) and slope-m which are specified in the AASHTO M320 specification. The data is shown for the BBR data for the GSE material (Anderson, AAPT 2011) to illustrate what happens to the mastercurve as the material ages. The mastercurve at a reference temperature of -18^{o}C is plotted in Figure 10 for each of the aging conditions. It can be clearly seen that the master curve flattens as the material ages and in addition the time at which m=0.300 becomes longer as binders loses the ability to relax (square symbols on each line identify this point). The value of S(t)=300MPa as a solid bolded line on this plot. It can be seen that at the original condition the value where m=0.300 is at a location where the stiffness is greater than 300MPa. This binder in this condition is S-controlled. As the material ages the value of stiffness corresponding to the m=0.300 value reduces to below S(t)=300MPa denoting that the binder in an aged condition is now m-controlled.

Using the principles of time-temperature superposition the value of time in seconds can be translated to a ΔTc. This transformation is presented for the same data set in Figure 11. In the transformation to this a loading time of 60-seconds is used to represent the BBR stiffness since this the specified time at which stiffness and slope are computed in the specification and also for the ΔTc value. On this plot two values of ΔTc – one corresponding to the zero aging and the second corresponding to the maximum aging reported. The ΔTc value can be simply computed from the shape parameters describing the shape of the mastercurve along with the shift factor relationship. It should be noted that the position of the m=300 point depends upon the shape of the mastercurve (for example the R-value) and magnitude of the other parameters that are used to define the shape of the master curve. Consequently, the R-value would not be expected to produce a correlation as a sole parameter with the ΔTc value, but the ΔTc value is absolutely dependent upon the R-value and additional defining parameters (Gg, C1, C2, etc.).

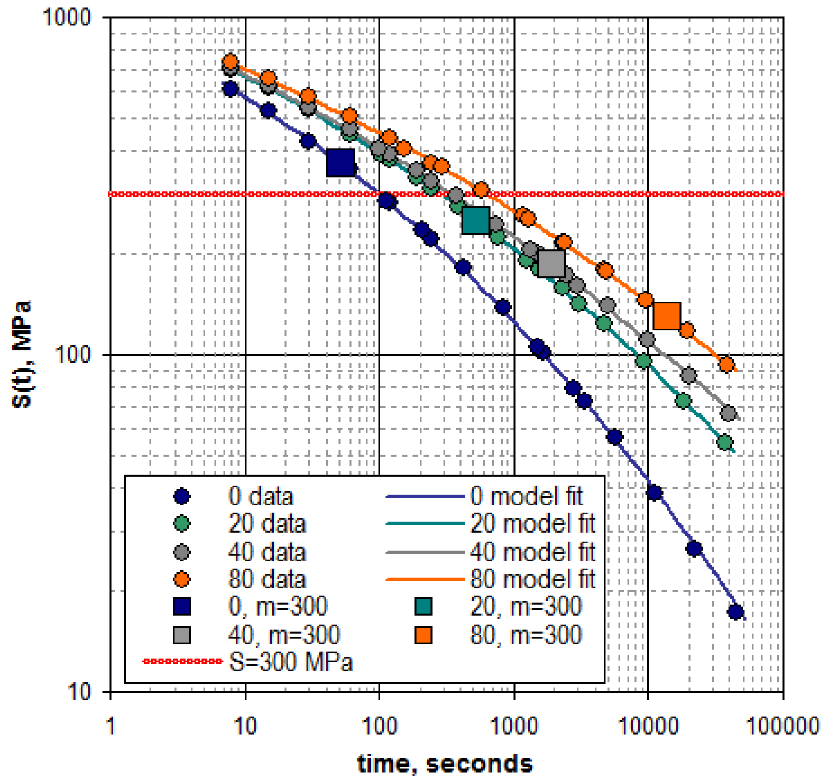

Figure 10: BBR mastercurve for binder data sets illustrating S(60)=300MPa and m-value = 0.300 (after Anderson et al., 2011)

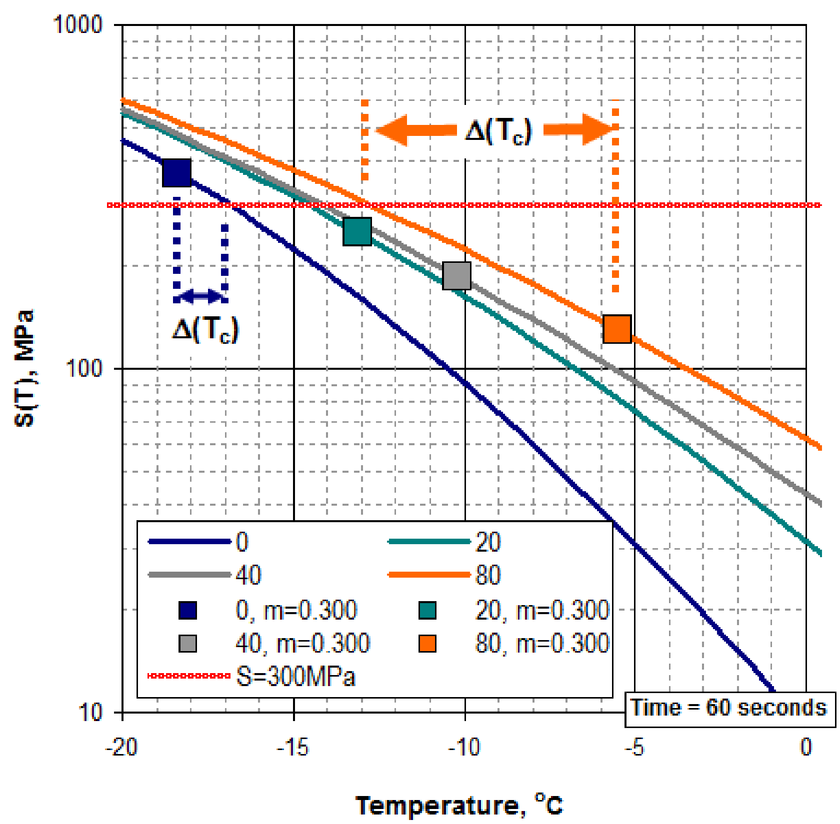

Figure 11: S(T) (t=60 seconds) for GSE binder showing determination of ΔTc (after Anderson et al., 2011)

The translation from G-R to DTc is best considered via the information in Figure 12. It should be noted that the parameter can be interrelated easily via the use of the CA model.

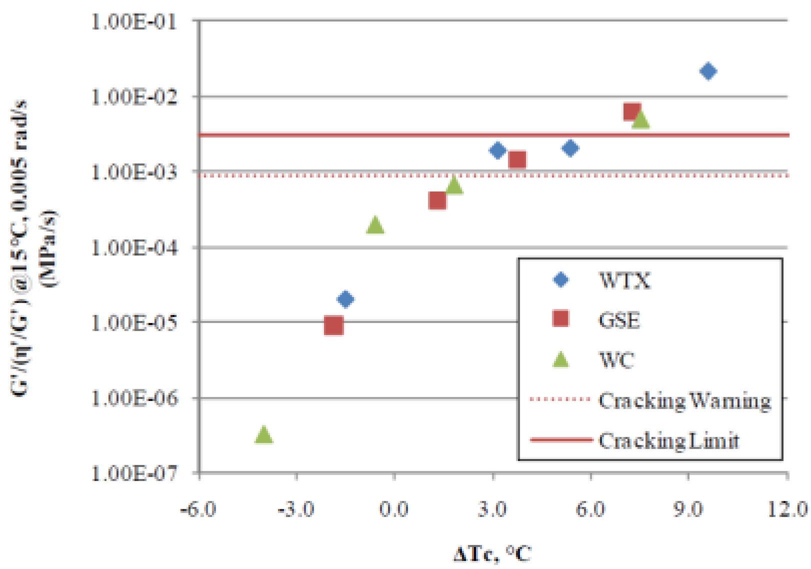

Figure 12: Glover viscosity function vs. ΔTc (note Glover viscosity function and Glover-Rowe parameter give the same information – one is just a simplified version of the other)

Other Comments

Some conflicting views on the value of the DENT test. One presentation sees this as being correlated to performance whereas other sees a limitation of the test. These two presentations are not in conflict but rather the presentations suggest a minimum practical limit for this test. This aspect should be further verified with data available to decide upon the usefulness of the procedure.

Consensus Items

- A concern exists from the agency/DOT perspective on the durability of asphalt surfacing
- ΔTc and G-R could both be used to track performance.
- ΔTc is used by more of the researchers since it is readily available in the data
- The amount of REOB generally effects the ΔTc – but not all materials are created equal

Proposed Next Steps

- Develop a synthesis document that summarizes this information and talks presentations/updates from September ETG meeting.
- Consult further with agencies/DOT and manufactures to develop more consensus items.
- Complete explicit math equations for use with different test schemes to demonstrate rheological aspects.
- Have this document ready for TRB meeting to be discussed – and available for this group in March 2015.