Evaluation of a 100% Rap Recycling Project in Fort Wayne, Indiana

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Abstract A project site investigation involving a high RAP (close to 100%) recycling has been evaluated to determine the performance differences with a control section, located in Fort Wayne, Indiana, one year after construction. The analysis involved cutting cores from the surface and determining recovered binder properties and mixture physical properties. Binder properties included standard PG grading in accordance with AASHTO M320 and the development of full master curves over the range of temperatures -30 to +80^{o}C. From the master curve analysis was conducted to look at parameters such as cross-over frequency, rheology index and viscos-elastic transition temperature. The data from this testing has been used in a manner to judge the effectiveness of a recycling oil, particularly when inspecting the relationship between cross-over frequency and rheological index. Mixture testing included evaluation of strength properties by conducting tests in bending beam rheometers and the development of mixture master curves. At the current time little difference is seen in the performance of the 100% RAP section compared to the control section, which provides significant support for continuing the effort to develop technologies for high percentage RAP recycling projects.

Keywords Recycling, RAP, Rejuvenation, Rheology.

1 Introduction

The recycling of HMA has been occurring for well over 40-years. However, due to changes in bitumen economic and environmental factors the need to recycle higher amounts of material has been increasing. The price of binder generally now tracks with other fuel commodities and the costs have risen significantly in the past years. In addition, with the increased environmental stewardship and factor such as taxes for extraction of aggregates and costs associated with disposal (if dumped) results in significant savings as the percentage of recycled material increases. This paper presents some of the trends that have been taking place in recycling in the USA and presents some of the developments that have been taking place in recent years with a high RAP hot-mix asphalt (close to 100% RAP) – termed HyRap®.

Recycling percentages in HMA vary by state and location dependent upon local specifications. It should be noted that each state department of transport (DOT) sets its own policies with regard to the percentages of recycled asphalt pavement (RAP) that is allowed in HMA. This combined with the various toll-road authorities and other organization with responsibility for highways results in some significant variability in specifications.

Asphalt mixture designs containing RAP follows the AASHTO M-323 standard that deals with "Superpave Volumetric Mix Design." This document notes that if the RAP content is less than 15% then no change in the binder selection is made. Above 15 percent and below 25% the recommendation by AASHTO is to use a grade softer binder. If 25% or greater rap is used then the recommendations from blending charts would be needed. These recommendations have been in place since the late 1990s. In the current version of AAHSTO M323 the RAP content is simply expressed as a percentage. However, a proposal from the Mixture Expert Task Group is that the RAP percentage should be changed to express the content as a RAP Binder Ratio (RAPBR) within the specifications rather than the percentage of RAP when considering the need to adjust the binder grade. This places emphasis on the binder content within the RAP rather than just the percentage of RAP and should be implemented within the specifications over the next couple of years. In practice several of the State DOTs have already changed the measurement to RAPBR instead of percent RAP. At the higher RAP contents (>25%) M323 requires a binder extraction to determine the "true" PG grade of the RAP binder. Extraction and recovery of asphalt binder is time consuming and involves hazardous chemicals creating a technical barrier for the use of higher amounts of RAP. Currently, little use is made of the extraction-recovery process; instead state specifications generally have been modified to allow use of a softer grade of asphalt binder to a higher RAP rate. The highest such upper limit has been set at 40%.

Of course it is important to ensure that the RAP mix will have a binder blend with the correct rheology to function over the range of high and low temperature experienced by the pavement. The Indiana DOT performed two studies prior to setting new RAP binder selection grades (Beeson et al. 2011; McDaniel et al. 2012). In the first numerous stockpiles of RAP were sampled and the asphalt binder was recovered to inventory grades of asphalt binder. Second a series of plant mixes were produced for mixtures containing up to 40% RAP. On the basis of these studies INDOT changed the specification to allow no change of asphalt binder grade up to 25% RAP and lowering of one grade (high temperature and low temperature) if RAP is greater than 25% but no more than 40%.

2 Black rock or usable binder

One of the questions that have resulted in significant discussions is – does the binder act in a functional manner or is RAP purely “black rock.” This aspect has been studied in practice by three different types of studies. These are: 1) evaluation of RAP mix stiffness properties; 2) assessment of RAP binder diffusion; and 3) determination of RAP mixture fracture properties.

In RAP mix stiffness evaluation, the predicted versus estimated complex dynamic stiffness modulus, E* of the mixture are determined. The measured results are compared to that which would be predicted from the recovered binder and aggregate properties (volumetric proportions) using the Hirsch model developed by Christensen et al. (2003). In this procedure first a complex dynamic modulus mastic curve (E*) is constructed for a mixture and then using the Hirsch relationships the binder stiffness is estimated for the blend of RAP and virgin binder. The back-calculated complex shear modulus, G*, values for the binder are then compared to those for conventional binder (containing no RAP binder) (West et al. 2013; Rowe 2012). While this method has been used to assess the incorporation of RAP binder, the changes in performance during early life (Kriz 2014) make this procedure somewhat problematic in that the degree of co-mingling of the binder can change.

The mixing of new binder with existing binder can be considered as a diffusion problem which is time and temperature dependent. Work conducted by Kriz (2014) suggests that the diffusion occurs at different rates during the early life of an asphalt mixture. The most rapid diffusion occurs while the mix is hot during the mixing and compaction process and then slows down as the mix cools. Diffusion continues during service but at a significantly reduced rate. The time for complete diffusion of a RAP binder with a new virgin binder following mixing, laydown and placement could be nearly immediate to a few months or even years depending on the thermal history provided. Kriz (2014) also noted that the effective viscosity of the blend was lower in the condition where complete diffusion had not occurred which would result in a less stiff material than would be estimated from a complete blending estimation – typically associated with the blending of recovered binders.

The evidence suggests that a large volume of the binder in the RAP can be considered as functional binder although some of the absorbed binder and/or heavily oxidized binder does not completely re-blend. The blending, while not immediate, generally appears to be relatively complete after a few months. However, effective performance is considered key, and currently most DOTs are keen for mixture tests such as those that will evaluate the fracture properties after the material has been mixed. While this only evaluates limited conditions it is seen as a way of ascertaining the product quality and performance at the production and lay-down stage using equipment and procedures that can be easily incorporated into project specifications. Methods being considered for fracture evaluation include tensile tests, bending beam fatigue (AASHTO M321), the Texas Overlay Tester and other measures of fracture properties.

3 Binder rejuvenation

Binder rejuvenation has been applied since the 1970s. While the use of softer binder grades as discussed above is used in the majority of the US market we note that the rejuvenation is now part of the process commonly used with RAP mixtures with many rejuvenators in the market place.

As binders age absorption and oxidative reactions result in significant changes to both physical and chemical properties. The changes in physical properties can be captured by conducting rheological studies of the binder. Two major effects occur, the binder hardens and the relaxation properties change consistent with the binder oxidizing. The change in rheology can be accessed via determination of the “Rheological Index” (Christensen and Anderson 1992; Rowe 2014) and the hardening can be assessed by determination of the frequency at which the phase angle is 45^{o} at as standard temperature – often termed the crossover frequency, see Fig. 1. If we express the CA model as:

$$G^*(T,\omega_r) = G_g\left[1+\left(\frac{\omega_c}{\omega_r}\right)^{\beta}\right]^{\frac{-\kappa}{\beta}} \quad (1)$$

where:

$G^*(T, \omega_r)$ = Complex shear modulus at temperature (T)
G_g = Glassy modulus
ω_c = cross over frequency
ω_r = reduced frequency of interest
β and κ = fitting parameters

When expressed in this form the “Rheological Index” or R value as used in the original Christen-Anderson model is equal to (log 2)/β. If the temperature susceptibility parameters are defined with a master curve then typically either a WLF or a modified Kaelble will provide the best fit to the data (Rowe and Sharrock 2011). Since a Kaelble defaults to a WLF when data only occurs above the defining temperature this relationship is more universal in dealing with the full temperature range and consequently this method is used in developing expressions since it is more inclusive of data types. The modified Kaelble is defined as follows:

$$\log \mathrm{a}_T = -C_1\left(\frac{T - T_d}{C_2 + |T - T_d|} - \frac{T_r - T_d}{C_2 + |T_r - T_d|}\right) \tag{3}$$

where:

T_d = defining temperature for inflection point
T_r = reference temperature
C_1 and C_2 = fitting constants

Where the reduced frequency is expressed as:

$$\omega_r = \log \mathrm{a}_T \times \omega \quad (\omega = \mathit{frequency}) \tag{4}$$

Mookhoek (2013) made use of rheological data when evaluating materials with a Black space plot of G* vs. phase angle (δ). He commented about RAP mixes he evaluated that damage levels can be described by the Glover–Rowe function which describes the relationship between G* and δ. This type of evaluation has been used by several researchers recently to explain a non-load associated distress in asphalt binders since it effectively characterizes the stiffness and relaxation properties (King et al. 2012). In addition, it will be one of the methods considered in the project being conducted by Texas A&M University considering these materials (NCHRP 9-58 Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios) (Daniels 2014). The cracking potential of three asphalt binders are shown at four different conditions in Fig. 2. As the binders are subjected to greater ageing they approach a region in the Black space plot shown as the damage zone. Results below this region generally show little or no cracking whereas results above this region are generally associated with cracked pavements.

This approach is similar in concept to the understanding that is obtained by inspecting the G^*_{VET} versus VET temperature that has been used to evaluate the performance of binders in the UK (Widyatmoko et al. 2004). A direct correspondence exists between the VET parameters and those of the Christensen-Anderson (CA) model has been demonstrated (Rowe 2014).

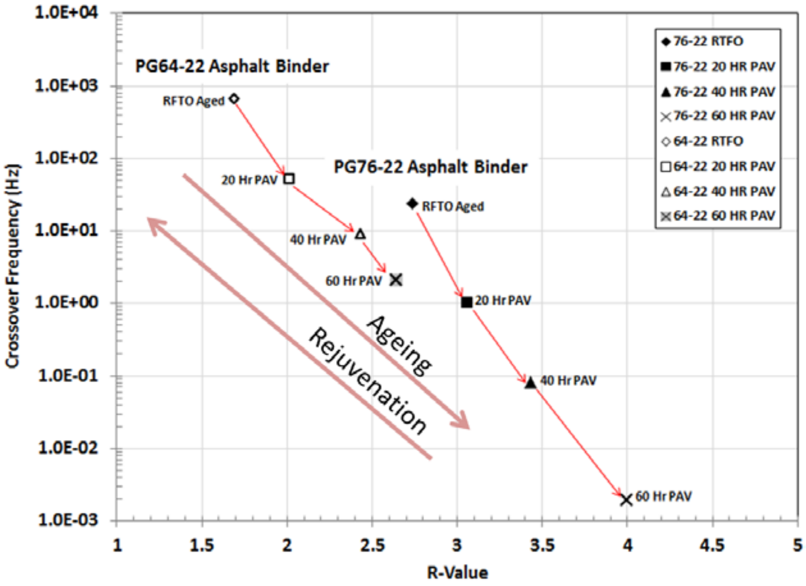

Fig. 1 Changes to R-value and Crossover frequency during aging (after Bennert, 2014)

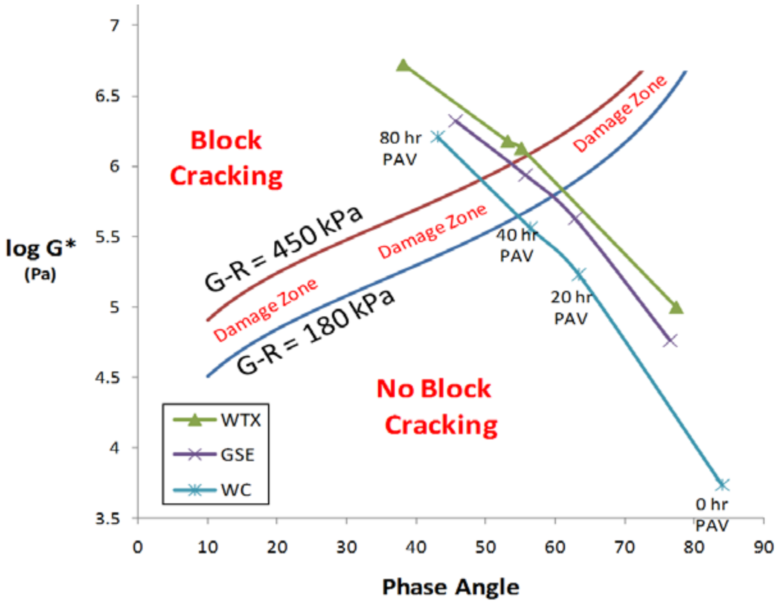

Fig. 2 Characterization of cracking potential by the Glover-Rowe parameter within a Black-Space plot

4 Improvement in mix design

The concept of a balanced mix design approach has been implemented in several projects following completion of a research study by Zhou et al. (2013). In this method the asphalt binder, aggregate and RAP are first combined in a manner that meets the requirements of a standard such as M323 in which gradation and binder properties are satisfied. The compaction to maximum density is checked to ensure that the mixture does not produce less than 2% air voids (or is less than 98% of the theoretical maximum density).

Two performance tests are used which relate to deformation/moisture damage and cracking propensity which are the Hamburg Wheel Tracking Test and the Texas Overlay tester respectively. A typical mix design requirement may be <0.5 inches in the Hamburg device and >300 cycles in overlay tester. These tests are performed on specimens compacted to a nominal 7% air void content whereas the volumetric evaluation produces void contents associated with a given number of gyrations used for conventional mixtures within that region. Each of these criteria results in allowable binder content and the design binder content is taken as the lowest binder content for cracking resistance or the highest binder content for rutting resistance. Zhou et al. (2013) did note that in some cases that the cracking criteria initially proposed had to be relaxed in designs. However, these mixes still seemed to perform better or equal to conventional mixes. If a similar scheme is implemented in other areas then the test types may change based upon the local experience of a particular agency with materials in a given region.

5 High Rap Mixes

HMA with high rap contents (above 75%) have been used in the USA for a number of years in either an experimental or pioneering manner. For example a technology called CYCLEAN was implemented in the Los Angeles area of California in 1988 (Martin, 1992) and was manufacturing high 100% RAP mixtures with an oil-based rejuvenating agent added to restore flexibility to the asphalt binder (Environment & Energy Management, EPRI Industrial Program, 1992). More recently other technologies have been implemented that produce mixtures to high standards with consideration of more modern design methods such as that with AASHTO M323. An example of a recent innovation in this area is the Hy-Rap® process implemented in Fort Wayne, Indiana (Gallivan, 2013). In this process fractionated RAP (FRAP) is fed through multiple entry points in a drum mix plant which has been specially modified to minimize the production of smoke from flame contact with the old RAP binder (see Fig. 3).

This plant has been in use for several years and recently Rowe et al. (2013) reported on the performance of Eggeman Road project in the area (see Fig. 4) which was cored for samples after a year in service. The roadway was originally repaved in August 2012 whereas coring took place in April 2013. At the time of construction no difference was observed between the performances of the HyRap materials versus the control sections placed. Five locations were evaluated and from each location 5 cores were taken in a line so that each core would have a similar void content and effects of any transverse variability would be minimized.

Test conducted on the cores including mixture volumetrics, binder and mix properties. The binder properties included evaluation of the master curves as shown in Fig. 5. In this testing it was not possible to distinguish between the performance of the binders and further calculations of the R-value and cross-over frequency confirmed that no significant difference existed between the Control and HyRap sections which suggested that the rejuvenator used had restored the binder. Testing of the complex modulus of the mixture also showed similar results for all the locations.

Fig. 3 Plant used in Fort Wayne, Indiana to produced 100% RAP mixes (after Gallivan, 2013)

In addition to stiffness testing the tensile strength was also evaluated. This testing was conducted on a small beam cut from the cores and done at a temperature that would result in a brittle type fracture. This revealed slightly higher strengths for the HyRap sections. However, when this was contrasted to the marginally lower void contents of these sections the performance became indistinguishable as shown in Fig. 6. This road was inspected again in June 2014 and the spring of 2015 and with the exception of some very minor distress the road appears to be functioning very well.

Fig. 4 Eggeman Road, Fort Wayne, Indiana – shortly after construction with overly containing 100% recycled asphalt

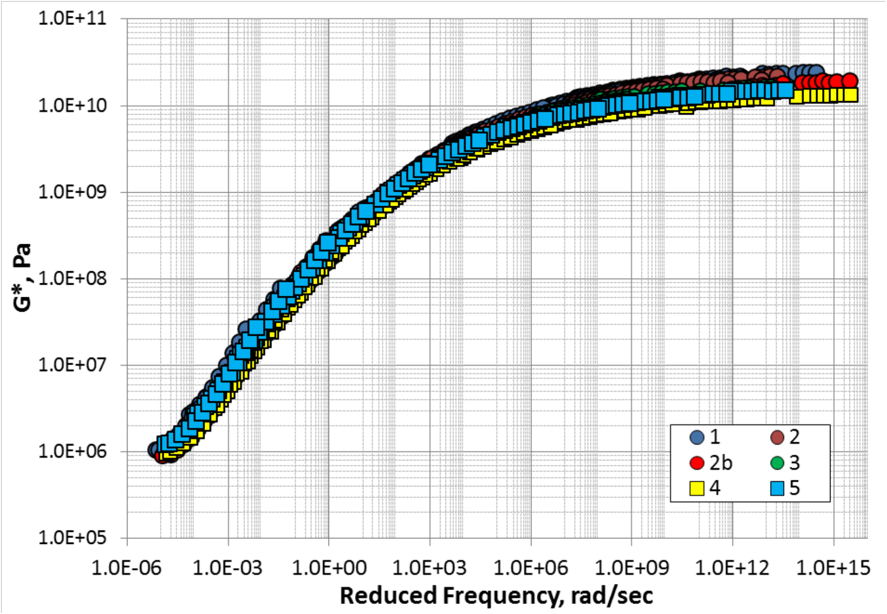

Fig. 5 Master curves of complex modulus, G*, of the binder recovered from mix samples after one year of service ($T_{ref} = 25^{o}C$) – references 1 to 3 are HyRap sections whereas 4 and 5 are the Control sections

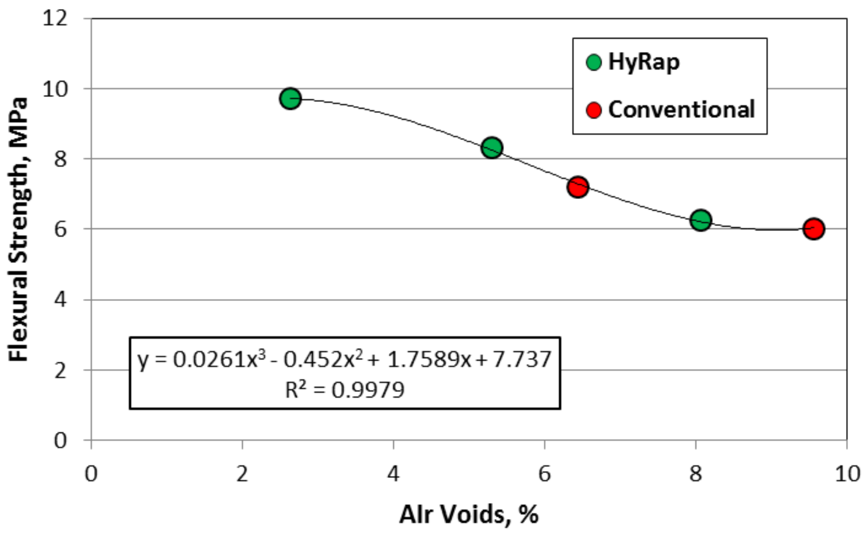

Fig. 6 Relationship between air voids and flexural strength

6 Summary

The discussion in this paper provides a view on some of the implementation of RAP mixes in the USA. The use of RAP is common place. The emergence of technologies to produce high RAP mixtures is also gaining some momentum with several plant manufactures offering options for equipment that will produce mixtures with greater than 70% RAP content.

In the design of RAP mixtures it is important to consider the binder properties that will be achieved over the full range. In the USA this is done by considering the AASHTO M320 specification properties and ensuring that high, low and intermediate properties are all satisfied when designing a RAP mixture. This is critical to ensure the range of rheological parameters for performance is obtained and to prevent early life cracking.

The concept of a balanced mix design ensures that adequate properties will be achieved for the major distress modes that affect a pavement structure and places an emphasis on the physical properties of the RAP mix rather than compliance with recipe specifications. This approach has already been shown to reduce the occurrence of cracking in some projects in Texas and shows significant promise for future implementation.

The use of high RAP mixtures have been evaluated for an example project in Fort Wayne, Indiana has illustrated that identical performance can be obtained when compared to conventional mixtures. The use of asphalt mixtures containing greater than 70% RAP is occurring with a number of different manufactures in several USA states. This type of technology is being evaluated by various agencies and will continue to be implemented as plants and technologies improve over the years.

Environmental stewardship and economic cost savings will result in a continued use of RAP and while this type of mix was once a rarity in the asphalt industry it has now become common place along with the need for technologists to understand how these materials behave.

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References

Beeson M, Prather M and Huber G (2011) Characterization of Reclaimed Asphalt Pavement in Indiana: Changing INDOT Specification for RAP. Transportation Research Board Meeting, Washington, DC

Bennert T (2014) Personal communications. Rutgers University, New Jersey, 2014.

Christensen, D.W. and Anderson, D.A., "Interpretation of Dynamic Mechanical Test Data for Paving Grade Asphalt," Journal of the Association of Asphalt Paving Technologists, Volume 61, 1992, pp. 67-116.

Christensen DW, Pellinen T and Bonaquist RF (20003) Hirsch Model for Estimating the Modulus of Asphalt Concrete. Journal of the Association of Asphalt Paving Technologists

Daniels J (2014) NCHRP 9-58 Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios. September Binder/Mixture ETGs

Environment & Energy Management, EPRI Industrial Program (1992) Microwave Process for Asphalt Pavement Recycling. Techapplication, Issue No. 2

Gallivan V (2013) Status of Reclaimed Asphalt Pavement use in North America. HighRAC Workshop, TU Delft, Netherlands

King GN, Anderson RM, Hanson DI and Blankenship PB (2012) Using Black Space Diagrams to Predict Age-Induced Cracking. 7th Rilem International Conference on Cracking in Pavements, Delft NL

Kriz P (2014) Asphalt Diffusion. 59th Canadian Technical Asphalt Association Annual Conference, Winnipeg, Manitoba, Canada, November, 2014

Martin H (1992) Facility Allows City to Recycle Its Roadways: Environment: Thanks to L.A.'s Pacoima asphalt treatment plant, fewer highways end up down in the dumps. Los Angeles Times, November 2nd, 1992.

McDaniel R, Shah A, Huber G and Copeland A (2012) Effects of Reclaimed Asphalt Pavement Content and Virgin Asphalt Binder Grade on Properties of Plant Produced Mixtures," Journal of Road Materials and Pavement Design, Volume 13, No. S1, pp. 161-182.

Mookhoek SD (2013) PMB properties in 2LPA, The effect of ageing on raveling resistance. HighRAC Workshop, TU Delft, Netherlands, June 4th, 2013.

Rowe G.M (2014) Interrelationships in Rheology for Asphalt Binder Specifications.59th Canadian Technical Asphalt Association Annual Conference, Winnipeg, Manitoba, Canada, November 2014.

Rowe GM (2012) Rheology considerations for recycled and recovered binder. Presentation at the Pavement Performance Prediction Symposium - Binder Issues Affecting the Durability of RAP and WMA Pavements, Research Institute, Laramie, Wyoming, July 12th 2012.

Rowe GM and Sharrock MJ (2011) Alternate Shift Factor Relationship for Describing Temperature Dependency of Viscoelastic Behavior of Asphalt Materials, Transportation Research Record, Journal of the Transportation Research Board, No. 2207

West R, Willis JR and Marasteanu M (2013) Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content. NCHRP Report 752, National Cooperative Highway Research Program

Widyatmoko I, Elliott RC and Heslop MW (2004) Mapping Crack Susceptibility of Bituminous Materials with Binder Durability. 5th International RILEM Conference, Limoges, France

Zhou F, Hu, S and Scullion T (2013) Balanced RAP/RAS Mix Design and Performance Evaluation System for Project-Specific Service Conditions. Report 0-6092-3, Texas A&M Transportation Institute