Transportation Literature Search

Prepared by
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Wisconsin Department of Transportation Research and Communication Services

Recycled Asphalt Pavement Levels in Flexible Pavement

Prepared for
Wisconsin Highway Research Program
Flexible Pavements Technical Oversight Committee

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Transportation Literature Searches are prepared for WisDOT staff and principal investigators to heighten awareness of completed research in areas of current interest. The citations below are representative, rather than exhaustive, of available studies on the topic. Primary online resources for the literature searches are the Transportation Libraries Catalog (TLCat), the Transportation Research Information Service (TRIS Online), National Transportation Library (NTL), Research in Progress (RiP) Compendex/Engineering Village, Web of Science, and other academic and scientific databases when requests merit. Online copies of publications are noted when available. Hard copies of cited literature may be obtained through the WisDOT Library; contact John Cherney at john.cherney@dot.state.wi.us or 608-266-0724.

SUMMARY
Our search of the above databases found 15 reports and articles pertinent to use of Recycled Asphalt Pavement in asphalt pavement construction at more than minimal levels – that is, ranging from 25 to 100 percent. Of these citations, six originate from federally managed research sources (including the Transportation Research Board and FHWA), five from trade newsletters and journals, two from academic journals and conferences, and one each from the states of Minnesota and Oklahoma. Of the 15 reports, 10 were published in 2004, 2005 and 2006, with a high of five in 2005; the remaining five citations originate in the years 2000 through 2003.

KEYWORDS
RAP, flexible, asphalt, pavement, level, content, recycled asphalt

CITATIONS

Title: Will high paving cots put recycled roads back in the fast lane?
Author(s): Tudor Hampton
Date: June 2006
Doc ID/URL: *Engineering News Record*, Vol. 256 (25), June 26, 2006: 70.
Description: 1 p.
Contents: The increase in the price of liquid asphalt of more than 40% is making highway contractors to recycle millions of tons of asphalt pavements. Asphalt, the syrupy glue that binds flexible pavement, makes up 5% on average of the total raw material in a road. Recycling experts claim that equipment and methods are available to process large quantities of reclaimed asphalt pavement (RAP) with Superpave quality. The highway contractors are looking forward to increase the RAP content due to the rise in paving costs. Most of the contractors agree that more RAP content in roads would stretch the budgets, so IDOT planned to develop new RAP guidelines that would be soon effective. The increased recycling could reward the contractors with lower costs that yields larger profits.

Title: Evaluating Recycled Asphalt Pavement Mixtures Using Mechanistic-Empirical Pavement Design Guide
Author(s): Jo Sias Daniel, Ghassan R. Chehab
Date: 2006
Doc ID/URL: Report No. 06-2774, 2006 TRB 85th Annual Meeting Compendium of Papers CD-ROM.
Description: 19 pp.
Contents: The main objectives of this paper include understanding the influence of RAP content on mixture behavior, and assessing the sensitivity of assumed binder grade on performance prediction. Those tasks are achieved by utilizing mechanistic-empiric software to predict the performance of a specific flexible pavement structure with a RAP modified HMA surface layer. Different design runs are conducted for which all the pavement properties and conditions are held constant except for the properties of the surface layer. Specifically, a near-full factorial

experiment is performed where RAP content and effective binder PG grade are the main variables. Comparison of the predicted performance of the various runs reveals important findings on the extent and manner that those two properties affect pavement distresses and performance. The influence of the assumed PG binder grade, particularly the high temperature grade, for the RAP mixtures has a significant influence on the predicted amount of thermal cracking and rutting for the given structure. The predicted performance is especially sensitive to changes in assumed PG grade in the range where the true effective PG grade is expected to fall; the difference from on PG grade to another can be the difference between a well performing mixture and one that requires redesign. The results emphasize the importance of determining the effective binder grade of RAP mixtures. An added benefit of conducting the numerous software runs is the identification of issues that need to be considered when incorporating RAP mixtures in pavement design using the software.

Title: Research Pays Off: Designing Superpave Mixes with Locally Reclaimed Asphalt Pavement: North Central States Jointly Fund Study
Author(s): Rebecca McDanial, Tommy Nantung
Date: 2005
Doc ID/URL: *TR News*, No. 239: 28-30. http://gulliver.trb.org/publications/trnews/trnews239rpo.pdf.
Description: 3 pp.
Contents: This article discusses the results of a study that expanded upon National Cooperative Highway Research Program (NCHRP) Project 9-12, Incorporation of Reclaimed Asphalt Pavement in the Superpave System, by investigating materials common to the North Central region, as well as studying the use of a higher reclaimed asphalt pavement (RAP) content. The study results showed that acceptable Superpave mixtures could be designed with as much as 40% to 50% RAP, although the gradation and aggregate quality may limit the amount of RAP that can be used. States in the North Central region report that, in general, RAP use is returning to the levels common before Superpave. As a sponsoring state, Indiana conducted a cost benefit analysis of the research project as part of an independent review of the cost effectiveness of the U.S. Department of Transportation's research program. A conservative estimate indicates that the Indiana Department of Transportation has saved nearly $330,000 per year when adding only 5% RAP to more than 5 million tons of base and intermediate mixes--although RAP contents of 15% to 20% are more typical.

Title: A blend of technologies
Author(s): Patrick Smith
Date: 2005
Doc ID/URL: *World Highways / Routes du Monde*, Vol. 14 (7): 50-51.
Description: 2 pp.
Contents: Asphalt plant producers are playing a significant role in boosting the popularity of asphalt recycling by manufacturing plants that are capable of recycling reclaimed asphalt pavement (RAP). Although many recycling plants are designed for large operations, this article describes a new plant, aimed at the smaller contractor market, that offers portability and low capacity. The plant is capable of producing hot mix asphalt mixes with up to 50% RAP content and is suitable for projects involving low-volume roads or city streets. The unit uses a counter-flow design, a configuration that makes it easier for producers to obtain permits for operation in states that have strict air quality regulations.

Title: Lessons Learned from the Long-Term Pavement Performance Program and Several Recycled Sections in Texas
Author(s): Dar-Hao Chen, Jerome Daleiden
Date: 2005
Doc ID/URL: *Transportation Research E-Circular No. E-C078*: 70-84.
Description: 15 pp.
Contents: The performance of recycled asphalt pavement (RAP), the effects of milling, and overlay thickness are important factors for pavement engineers to consider when making decisions on rehabilitation and maintenance activities. Specific Pavement Studies- (SPS-) 5 sections were built 10 years ago to address this issue. Performance data under well-documented SPS sections have provided valuable insight that could not have been achieved otherwise. SPS-3, SPS-5, and three hot-in-place (HIP) recycled sections were studied. One of the HIP recycled sections was adjacent to an SPS-3 and an SPS-5 section, thus they all possessed the same underlying subsurface layers. It was found that after more than 10 years of service, the RAP sections perform as well as the virgin asphalt concrete (AC) sections. This indicates that the RAP can be effective when used properly. Also, little difference was found in terms of performance on milled and non-milled sections. However, to date, there is less distress on the 125-mm sections than on the 50-mm sections. It is important to note that all SPS-5 sections are able to resist reflective cracking when a mixture of 30% RAP and a softer binder is used, the result is a high penetration number (30 to 45),

with a flexible mixture able to resist cracking. In contrast, cracks came through the HIP recycled sections in just a few weeks for US-175 and US-84. Low penetration numbers in the range of 20 to 21 were found. A 75% mixture of RAP was found to be too high, because aged binder tends to become brittle, and consequently does a poor job resisting cracking. The HIP recycled process was used satisfactorily on US-281 where no cracking potential existed. Thus, it was concluded that high percentage RAP mixture should not be used on any location where cracking potential is present. Also, a lower viscosity AC should be added to the RAP to increase the flexibility. The results in the SPS-3 sections indicated that chip seal is the most cost-effective, preventive maintenance (PM) treatment. Although rehabilitation strategy on SPS-5 sections costs more than PM treatments on SPS-3 sections, SPS-5 sections performed better than the SPS-3 sections. The most important factor influencing pavement performance on SPS-3, SPS-5, and HIP recycled sections is the type of surface treatment.

Title: Mechanistic and volumetric properties of asphalt mixtures with recycled asphalt pavement
Author(s): Jo Sias Daniel, Aaron Lachance
Date: 2005
Doc ID/URL: *Transportation Research Record 1929*, 2005: 28-36.
Description: 9 pp.
Contents: This research examines how the addition of recycled asphalt pavement (RAP) changes the volumetric and mechanistic properties of asphalt mixtures. A Superpave [registered trademark] 19-mm mixture containing 0% RAP was the control for evaluating properties of mixes containing 15%, 25%, and 40% RAP. Two types of RAP were evaluated: a processed RAP and an unprocessed RAP (grindings). Testing included dynamic modulus in tension and compression, creep compliance in compression, and creep flow in compression. Dynamic modulus and creep compliance master curves were constructed with the use of the time-temperature superposition principle to describe the behavior of each mix over a range of temperatures. The voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) of the RAP mixtures increased at the 25% and 40% levels, and there was also an influence of preheating time on the volumetric properties. The dynamic modulus of the processed RAP mixtures increased from the control to 15% RAP level, but the 25% and 40% RAP mixtures had dynamic modulus curves similar to that of the control mixture in both tension and compression. The creep compliance curves showed similar trends. A combination of gradation, asphalt content, and volumetric properties is likely the cause of these trends.

Title: Testing of RAP materials for overlay design standards
Author(s): Rafiqul A. Tarefder, Musharraf M. Zaman, Cheong F. Ting
Date: 2005
Doc ID/URL: *Proceedings of the Construction Research Congress 2005: Broadening Perspectives, Apr. 5-7, 2005*: 1089-1098.
Description: 10 pp.
Contents: Cold-mixed, cold-laid (CMCL) rehabilitation or cold recycling is a technically promising and cost effective method for improving distressed asphalt pavements. Unlike hot mix recycling, cold recycling lacks field and laboratory performance data. Also, there is no widely accepted CMCL design and testing standards available. This study has generated useful field and laboratory data on pavement overlay constructed with 100% recycled asphalt pavement (RAP) and the CMCL technique. The laboratory tests conducted in this study include physical property, strength and performance-related tests. While property tests include moisture content, gradation, specific gravity, emulsion content, aggregate properties, coating and adhesion; strength and performance tests include resistance, indirect tensile strength, moisture-induced damage susceptibility, and rutting. In addition, two field case studies are conducted; one overlay job was quite successful but the other exhibited relatively poor performance. Causes of differential performance are examined.

Title: Validation of performance-based method for determining rejuvenator content in HMA
Author(s): Junan Shen, Baoshan Huang, Yoshitaka Hachiya
Date: June 2004
Doc ID/URL: *International Journal of Pavement Engineering*, Vol. 5 (2), June 2004: 103-109.
Description: 7 pp.
Contents: This paper presents the results of a laboratory study in which the recommended values of rejuvenator contents from previous binder studies were validated through laboratory mixture performance tests. The experiments consisted of the comparison of recycled asphalt mixtures at three rejuvenator contents: 0, 2.0 (lower recommended limit) and 7.4% (upper recommended limit). In addition, a control mixture with virgin asphalt binder was also included in the experiment. The mixture performance tests included the wheel tracking at 60°C and low temperature thermal stress restrain specimen (TSRS) tests. The results from this study indicated that: (1) the properties of HMA using recycled asphalt binders with the recommended rejuvenator contents from the previous studies were comparable to the control virgin mixture; (2) it was more reliable to use the median recommended rejuvenator

contents for mixtures with both satisfactory high temperature stability and low temperature fracture resistance and (3) the rejuvenator content affects significantly the properties of recycled mixtures in a similar way to that of the properties of recycled asphalt binders, by increasing low temperature grade and decreasing high temperature grade.

Title: The Superpave RAP
Author(s): M. Fickes
Date: 2004
Doc ID/URL: *Hot Mix Asphalt Technology*, Vol. 9 (2), March/April 2004: 16-20.
Description: 5 pp.
Contents: Using reclaimed asphalt pavement (RAP) in Superpave mixes is becoming increasingly popular. Superpave itself has grown in popularity since it was introduced a decade ago, with as many as 40 state DOTs now using Superpave versus a mix design system such as Marshal and Hveem. Superpave, a system that matches mixes to traffic and climate, did not come with specifications for using RAP in mixes. However, interim guidelines suggested that mixes with up to 15 percent RAP would probably require no change in specification, while the guidelines suggested that mixtures drop one increment in binder grades for mixes with a RAP content between 16 and 25 percent. They also called for the use of binder blending charts when RAP content rises about 25 percent. Studies conducted since that time have given a more definitive set of guidelines for use of RAP. A study conducted by the National Cooperative Highway Research Program confirmed that the interim guidelines are appropriate. The study also found that Superpave mixes with up to 40 or 50 percent of RAP can be designed; that poor aggregate properties can counteract the effect of binder stiffening caused by RAP; and that regional differences in material characteristics affect the quality of asphalt mixes employing RAP.

Title: Recycled Asphalt Pavement (RAP) Effects on Binder and Mixture Quality
Author(s): Xinjun Li, Timothy R. Clyne, Mihai O. Marasteanu
Date: 2004
Doc ID/URL: MN/RC-2005-02, Final Report. http://www.lrrb.org/pdf/200502.pdf.
Description: 74 pp.
Contents: Recycled asphalt pavement (RAP) has been used in Minnesota for over 25 years. The most commonly used method is to mill material from an existing pavement and incorporate it into a new asphalt mix. Previous experience and specifications allow various RAP percentages depending on the traffic level. Past research has also shown the effects of RAP on both the high- and low-temperature properties of asphalt cement and the asphalt mixtures. Therefore, it becomes an important priority to study and determine the effects various types and percentages of RAP have on the asphalt cement and mixture quality. This will result in a rational design for asphalt mixture that contain RAP and could change the Minnesota Department of Transportation's asphalt specification.

Title: Use of reclaimed asphalt pavement (RAP) under Superpave specifications
Author(s): Rebecca S. McDaniel, Ayesha Shah
Date: 2003
Doc ID/URL: *Asphalt Paving Technology*, Vol. 72, 2003: 226-252.
Description: 27 pp.
Contents: The performance of Superpave asphalt mixtures incorporating RAP was investigated. Three RAP materials from Indiana, Michigan and Missouri were evaluated. Mixtures were designed and tested in the laboratory with each RAP, virgin binder and virgin aggregate at RAP contents up to 50 percent. The laboratory mixtures were compared to plant produced mixtures with the same materials at the medium RAP content of 15-25 percent. Binder and mixture tests were performed. The resultant data was analyzed in detail.

Title: Determination of Recycled Asphalt Pavement Content in Asphalt Mixes Based on Expected Mixture Durability
Author(s): O. Abdulshafi, M. Fitch, B. Kedzierski
Date: 2002
Doc ID/URL: FHWA/OH-2002/037, Final Report. http://www.dot.state.oh.us/research/2002/Materials/14734-FR.pdf.
Description: 102 pp.
Contents: Decreasing supplies of locally available quality aggregate in some areas, growing concern over waste disposal, and the rising cost of asphalt binder have resulted in greater use of recycled asphalt pavement (RAP) for new road construction. Unfortunately, the incorporation of RAP introduces one more variable to consider when predicting the durability of the newly constructed asphalt concrete pavement. Traditional determination of the RAP quantity allowed for addition to the virgin asphalt concrete mix has an empirical nature and is based on viscosity measurement of a blended binder. The primary objective of this study was to develop an implementable testing

procedure that will effectively determine recycled asphalt pavement (RAP) content limits based on mix durability loss. The research approach involved laboratory examination of twenty intermediate course bituminous concrete mixes, to evaluate changes in asphalt binder properties and mix durability resulting from the addition of various levels of RAP. Specimens of virgin asphalt binder and blended virgin/RAP binder were tested (both non-aged and oven-aged) by Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) to evaluate stiffness properties at various temperatures. Bituminous mix specimens compacted at optimum binder contents were tested (both non-conditioned and moisture-conditioned) for indirect tensile strength and absorbed energy characteristics. Non-conditioned specimens were also tested for unconfined compressive strength. The BBR test results indicate that creep stiffness of blended asphalt binder increases with increasing RAP content. The moisture damage test results indicate that RAP addition has an effect on the durability performance of bituminous concrete. A procedure based on the Absorbed Energy concept is suggested for use by the Ohio Department of Transportation for determining optimum RAP content when designing a bituminous concrete mix. Recommended values of Indirect Tensile Strength and Absorbed Energy (prior to aging and after aging) are provided for use in classifying potential durability performance of bituminous mixes containing RAP.

Title: Use of Reclaimed Asphalt Pavement (RAP) Under Superpave Specifications: A Regional Pooled Fund Study
Author(s): R. McDaniel, H. Soleymani, A. Shah
Date: 2002
Doc ID/URL: FHWA/IN/JTRP-2002/6, Final Report.
http://rebar.ecn.purdue.edu/JTRP_Completed_Project_Documents/SPR_2143/FinalReport/spr_2143_final.pdf.
Description: 79 pp.
Contents: This regional pooled fund project was conducted to investigate the performance of Superpave asphalt mixtures incorporating Reclaimed Asphalt Pavement (RAP). This study was closely coordinated with a national study on the same topic [National Cooperative Highway Research Program (NCHRP) 9-12, Incorporation of Reclaimed Asphalt Pavement in the Superpave System]. Specifically, this regional project looked at typical materials from the North Central United States to determine if the findings of NCHRP 9-12 were valid for Midwestern materials and to expand the NCHRP findings to include higher RAP contents. Three RAP materials from Indiana, Michigan and Missouri were evaluated. Mixtures were designed and tested in the laboratory with each RAP, virgin binder and virgin aggregate at RAP contents up to 50%. The laboratory mixtures were compared to plant produced mixtures with the same materials at the medium RAP content of 15-25%. Binder and mixture tests were performed. Briefly, the results showed that mixtures with up to 50% RAP could be designed under Superpave, provided the RAP gradation and aggregate quality were sufficient. In some cases, the RAP aggregates limited the amount of RAP that could be included in a new mix design to meet the Superpave volumetric and compaction requirements. Linear binder blending charts were found to be appropriate in most cases. In general, increasing the RAP content of a mixture increased its stiffness and decreased its shear strain, indicating increased resistance to rutting. It is important to consider the RAP aggregate gradation and quality in the mix design, since a poor aggregate structure could reduce mixture stiffness and ultimately performance. Provided the RAP properties are properly accounted for in the material selection and mix design process, Superpave mixtures with RAP can perform very well.

Title: Mix design using asphalt millings
Author(s): Rita I. Issa, Musharraf M. Zaman, Gerald A. Miller
Date: 2000
Doc ID/URL: Item 2148, ORA 125-6106, Summary Report. http://ntl.bts.gov/data/Millings_Final_Report.pdf.
Description: 45 pp.
Contents: A field demonstration project was undertaken by the Oklahoma Department of Transportation to investigate the performance of an asphalt overlay constructed using recycled asphalt millings and the cold mixed, cold laid system. A 1.9-km (1.2-mi) section of the US-64 North frontage road in Pawnee County was rehabilitated with a 5-cm (2-in.) thick overlay using 100% recycled asphalt millings. The section was divided into four approximately equal length test sections. A different type of emulsion was used to rejuvenate the asphalt millings for each test section. The purpose was to determine the relative performance of each emulsion type and construction method used in this recycled asphalt pavement (RAP) project. A laboratory investigation was carried out to accomplish two major tasks: the first task was to determine the optimum emulsion and moisture contents of RAP mixes prepared with four different types of emulsions; the second task was to investigate the effect of adding portland cement to RAP mixes, thus producing a cement-emulsion composite. One of the objectives of this study was to document the behavior of RAP mixes as affected by the addition of portland cement, and to find the optimum emulsion and cement contents. Achieving an adequate compaction is crucial to the successful performance of a cold mixed, cold laid overlay. The degree of compaction can greatly vary depending upon rolling pattern, speed, equipment, compaction dynamics, and characteristics of RAP mixes. From post-construction site visits, it was

evident that the polymer modified anionic (PMA) emulsion section performed better than the other sections. A PMA mix containing 2% free moisture and 2% emulsion was found to have the highest dry stability value; however, this mix had a lower retained stability than a comparable mix prepared with polymer modified cationic (PMC) emulsion. For samples prepared from cement-emulsion composite, both dry and soaked stability values increased as cement content increased. The addition of portland cement, however, affected the stability value of samples cured under soaked conditions much more than those cured under dry conditions. The introduction of as little as 1% of portland cement to RAP mixes doubled the retained stability of specimens, as compared with a RAP mix rejuvenated with high float emulsion (HFE-300). The cold mixed, cold laid process of pavement rehabilitation holds significant promise for the future. The current technology, however, needs improvement and refinement through further laboratory and field studies.

Title: Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method
Author(s): R.S. McDaniel, H. Soleymani, R.M. Anderson, P. Turner, R. Peterson
Date: 2000
Doc ID/URL: NCHRP Web Document 30. NCHRP Project D9-12, Contractor Final Report.
http://trb.org/trb/publications/nchrp/nchrp_w30-a.pdf,
Description: 461 pp.
Contents: This report is presented in four chapters. Chapter 1 reviews the background behind the project and discusses the research approach. Chapter 2 outlines the research findings from all parts of the project. Chapter 3 discusses the implications of these findings. Chapter 4 summarizes the applicable conclusions from this research, makes recommendations for future practice based upon these conclusions and suggests additional research that may be necessary to address some unresolved issues. The main research was conducted in three separate, but related, studies. The "black rock study" investigated the question of whether reclaimed asphalt pavement (RAP) acts like a black rock or whether there is, in fact, some blending that occurs between the old and new binders. The "binder effects study" examined issues related to RAP binder testing including extraction and recovery procedures, applicability of the AASHTO MP1 tests to RAP binders and the effects of RAP content and stiffness on blended binder properties. The "mixture effects study" was directed at assessing the effects of the added RAP on total mixture properties as measured by shear, indirect tensile and beam fatigue testing. Two small-scale investigations, termed "mini-experiments," investigated the comparison of laboratory specimens to plant-produced mixtures and the effects of heating time and temperature on RAP properties. Significant findings include the conclusion that RAP is not a black rock and significant blending does occur. This means that the use of blending charts is appropriate. Recommendations are included for the best laboratory procedures to use for development of these blending charts, including a modification of the Strategic Highway Research Program (SHRP) extraction/recovery procedure. Other findings strongly support the conclusion that there is a threshold level of RAP below which its effects are negligible. This level is between 10 and 20%, depending on RAP binder stiffness. These findings validate the three tiered approaches for RAP usage as recommended by the Mixture Expert Task Group. The appendices contain some of the supplemental documents developed during this research.