**Topic:** Evaluation of Curing Effects on Cold In-Place Recycled (CIR) Materials (LRRB NS 542)

**Date:** July 20, 2018  
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**Resources searched:** MnDOT Library catalog, TRID, RiP, Transport, State DOT Google custom search

**Summary:** Results are separated into U.S. Results and Non-U.S. Results (Canada and Europe). The curing period is discussed in many results. There wasn't much about GPR and RDM, but I added a note about the few that discussed these technologies. Full-text links are provided where possible. Please contact the library if you would like to request full text through inter-library loan (ILL).

**U.S. Results**

**Title:** Material Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt Concrete (NCHRP Report 863)  
**Authors:** Schwartz, Charles; Diefenderfer, Brian; Bowers, Benjamin  
**Source:** TRB - NCHRP (2017)  
**Abstract:** Recent improvements in asphalt emulsion chemistry that enable better aggregate coating, shorter curing times, and the elimination of solvents have substantially increased the applicability of mixtures produced by cold in-place recycling (CIR), cold central-plant recycling (CCPR), and full-depth reclamation (FDR). The objective of this research was to determine relevant properties of CIR, CCPR, and FDR materials with emulsified or foamed asphalt recycling/stabilizing agents for input into pavement structural design programs. The project developed a small-scale testing procedure that permits the measurement of the dynamic modulus and repeated load permanent deformation characteristics of field-produced and cured asphalt-stabilized, cold-recycled mixtures. These properties were determined for cold-recycled materials sampled from field projects across the United States. Suggested Level 3 modulus inputs were developed by the research team for use in structural design and analysis programs. Finally, structural analyses were conducted with these inputs in Pavement ME Design that demonstrated the sensitivity of the test data to the different stabilizing agents used in the various field projects.  
**Full-text available via** [http://www.trb.org/Main/Blurbs/176641.aspx](http://www.trb.org/Main/Blurbs/176641.aspx)

**Title:** Cold In-Place Recycling Characterization for Single-Component or Multiple-Component Binder Systems  
**Authors:** Cox, Ben; Howard, Isaac  
**Source:** Journal of Materials in Civil Engineering, vol. 28, no. 11 (Nov. 2016)  
**Abstract:** This paper investigates multiple-component binder (MCB) systems (e.g., 2.5% emulsion with 2% portland cement). This paper’s objective is threefold: (1) present a universal CIR design framework applicable to any cementitious and/or bituminous material; (2) demonstrate MCB sustainability advantages; and (3) conduct an extensive SCB and MCB characterization. Universal design framework components include specimen preparation, curing, and testing protocols. Nine binder combinations were tested for wheel tracking, permeability, modulus, strength, and cracking response. Cement SCBs yielded low cracking resistance, high rutting resistance, and favorable economics; emulsion SCBs yielded the
Title: Cold In-Place Recycling Moisture-Related Design and Construction Considerations for Single or Multiple Component Binder Systems
Authors: Cox, Ben; Howard, Isaac; Campbell, Colin
Source: Transportation Research Record, no. 2575 (2016)
Abstract: Moisture is one key area in which design and construction are often disconnected. This study’s objective, therefore, was to evaluate the moisture (and associated early-age strength and stability) aspects of CIR, particularly within a framework that could consider hydraulic cement, bituminous emulsion, or combinations of both binders. A universal design framework that accommodates any binder or combination thereof while representing early-age field conditions has advantages for agencies, not only in its reasonable characterization of construction processes, but also in its facilitation of competition and creativity in the process of selecting materials and proportions. This study was organized in three phases. Phase 1 documented moisture instrumentation of a cement CIR project. Data were successfully obtained throughout compaction and curing and were used in Phases 2 and 3 alongside supplemental field and laboratory testing. Phase 2 evaluated moisture’s role in compaction; Phase 3 evaluated moisture–strength and moisture–stability relationships for various curing protocols. Phase 2 concluded that high (>6%) moisture content, typical of Proctor compaction, is generally unnecessary. Thus, Proctor compaction is discouraged in favor of a fixed design moisture content. Phase 3 concluded that humid (35% to 50% humidity) and dry 40°C oven curing protocols are candidates for universal CIR design.

Title: Examination of Curing Criteria for Cold In-Place Recycling (Phase 3: Calibration of Moisture Loss Indices and Development of Stiffness Gain Model)
Authors: Lee, Hosin David; Woods, Adam; Kim, Yongjoo Thomas
Source: Iowa DOT and University of Iowa (Dec. 2011)
Abstract: In the previous study, moisture loss indices were developed based on the field measurements from one cold in-place recycling (CIR)-foam and one CIR-emulsion construction site. To calibrate these moisture loss indices, additional CIR construction sites were monitored using embedded moisture and temperature sensors. In addition, to determine the optimum timing of a hot mix asphalt (HMA) overlay on the CIR layer, the potential of using the stiffness of CIR layer measured by geo-gauge instead of the moisture measurement by a nuclear gauge was explored. Based on the monitoring of the moisture and stiffness from seven CIR project sites, the following conclusions are derived: 1. In some cases, the in-situ stiffness remained constant and, in other cases, despite some rainfalls, stiffness of the CIR layers steadily increased during the curing time; 2. The stiffness measured by geo-gauge was affected by a significant amount of rainfall; 3. The moisture indices developed for CIR sites can be used for predicting moisture level in a typical CIR project. The initial moisture content and temperature were the most significant factors in predicting the future moisture content in the CIR layer; and 4. The stiffness of a CIR layer is an extremely useful tool for contractors to use for timing their HMA overlay. To determine the optimal timing of an HMA overlay, it is recommended that the moisture loss index should be used in conjunction with the stiffness of the CIR layer.
Full-text PDF available: http://publications.iowa.gov/20078/

Title: Examination of Curing Criteria for Cold In-Place Recycling (Phase 2: Measuring Temperature, Moisture, Deflection and Distress from CIR Test Section)
Authors: Lee, Hosin David; Kim, Yongjoo; Im, Soohyok
Source: Iowa DOT and University of Iowa (March 2009)
Abstract: During this research, both temperature and moisture conditions were measured in the field by embedding the sensors at a midpoint and a bottom of the CIR layer. The main objectives of the research are to: (1) measure the moisture levels throughout a CIR layer and (2) develop a moisture loss index to determine the optimum curing time of a CIR layer before HMA overlay. To develop a set of moisture loss indices, the moisture contents and temperatures of CIR-foam and CIR-emulsion layers were monitored for five months. Based on the limited field experiment, the following conclusions are derived: 1) The moisture content of the CIR layer can be monitored accurately using the capacitance type moisture sensor; 2) The moisture loss index for CIR layers is a viable tool in determining the optimum timing for an overlay without measuring actual moisture contents; 3) The modulus back-calculated based on the
deflection measured by FWD seemed to be in a good agreement with the stiffness measured by geo-gauge; 4) The geo-gauge should be considered for measuring the stiffness of CIR layer that can be used to determine the timing of an overlay; and 5) The stiffness of CIR-foam layer increased as a curing time increased and it seemed to be more influenced by a temperature than moisture content. The developed sets of moisture loss indices based on the field measurements will help pavement engineers determine an optimum timing of an overlay without continually measuring moisture conditions in the field using a nuclear gauge.

Full-text PDF available: http://publications.iowa.gov/20071/

Title: Examination of Curing Criteria for Cold In-Place Recycling (Phase 1)
Authors: Lee, Hosin David; Im, Soohyok
Source: Iowa DOT and University of Iowa (March 2008)
Abstract: Cold In-Place Recycling (CIR) has been used widely in rehabilitating the rural highways because it improves long-term pavement performance. A CIR layer is normally covered by a hot mix asphalt (HMA) overlay in order to protect it from water ingress and traffic abrasion and obtain the required pavement structure and texture. Curing is the term currently used for the period of time that a CIR layer should remain exposed to drying conditions before an HMA overlay is placed. The industry standard for curing time is 10 days to 14 days or a maximum moisture content of 1.5%, which appear to be very conservative. When the exposed CIR layer is required to carry traffic for many weeks before the wearing surface is placed, it increases the risk of a premature failure in both CIR layer and overlay. This study was performed to explore technically sound ways to identify minimum in-place CIR properties necessary to permit placement of the HMA overlay. To represent the curing process of CIR pavement in the field construction, three different laboratory curing procedures were examined: 1) uncovered, 2) semi-covered and 3) covered specimens. The indirect tensile strength of specimens in all three curing conditions did not increase during an early stage of curing but increased during a later stage of curing, usually when the moisture content fell below 1.5%. Dynamic modulus and flow number increased as curing time increased and moisture content decreased. For the same curing time, CIR-foam specimens exhibited higher tensile strength and less moisture content than CIR-emulsion. The laboratory test results concluded that the method of curing, temperature and length of the curing period significantly affect the properties of the CIR mixtures. The moisture loss index was developed to predict the moisture condition in the field and, in the future, this index will be calibrated with the measurements of temperature and moisture of a CIR layer in the field.

Full-text PDF available: http://publications.iowa.gov/20058/

Title: Impacts of Curing Time and Moisture Content on Engineering Properties of Cold In-Place Recycling Mixtures Using Foamed or Emulsified Asphalt
Authors: Kim, Yongjoo; Im, Soohyok; Lee, Hosin David
Source: Journal of Materials in Civil Engineering, vol. 23, no. 5 (May 2011)
Abstract: A cold in-place recycling (CIR) layer is typically overlaid by hot-mix asphalt (HMA) to protect it from water ingress and traffic load. Most public agencies have different curing requirements that specify the number of curing days or the maximum moisture content for the CIR layer before placing the HMA overlay. However, these criteria are not well-founded on sound engineering principles and are often challenged by contractors, especially in inclement weather conditions. This study was performed to explore technically sound ways to identify the minimum in-place CIR properties necessary to permit the placement of an HMA overlay. The primary objective of this research was to determine how curing time and moisture content affect the development of indirect tensile strength, dynamic modulus, and flow number of CIR mixtures composed of foamed asphalt (CIR-foam) or emulsified asphalt (CIR-emulsion). On the basis of the limited test results, the indirect tensile strength of CIR specimens did not increase during an early stage of curing but increased during a later stage of curing, usually when the moisture content was less than 1.5%. Given the same curing time, CIR-foam specimens exhibited more tensile strength and less moisture content than CIR-emulsion specimens. Both dynamic modulus and flow numbers increased as the curing time increased and the moisture content decreased. Given the same moisture content, CIR-foam specimens exhibited higher dynamic modulus and larger flow numbers than CIR-emulsion specimens.

Full-text: https://ascelibrary.org/doi/10.1061/%28ASCE%29MT.1943-5533.0000209

Title: Evaluation of a Cold In-Place Recycled Rehabilitation Treatment
Authors: Henault, John; Kilpatrick, David
Source: Connecticut DOT (2009)
Abstract: In 1998, a state highway with fewer than 5,000 vehicles per day of traffic received a three-inch cold in-place recycled (CIR) base treatment to rehabilitate the pavement, which had developed extensive reflective cracking in a previous overlay. The CIR treatment was followed by a two-inch overlay to complete the preservation project. Adjacent pavement on this highway received a conventional HMA overlay, and served as the experimental control for this research. This report presents results of an evaluation of the CIR treatment after 10 years of service under light traffic. It includes results of testing of drilled cores and manual distress surveys. It also includes a state-of-the-art SPSS(trademark) statistical analysis of data collected by ConnDOT’s Photolog personnel. These data include rut depths determined from full-width and partial-width transverse profiling equipment, international roughness index (IRI) values, and WiseCrax pavement distress values. The WiseCrax analysis shows that the CIR treatment was an effective preservation technique that mitigated reflective cracking, as a 65% reduction in pavement cracking was observed for the CIR versus the control pavement. The density of drilled cores taken from the CIR base ranged from 80% to 90% of the maximum theoretical density (MTD). Accordingly, rutting is a concern when using a CIR treatment. Overall, rut depths were 10% less severe for the CIR rehabilitated pavement than for the control pavement; however, where longitudinal joints were located in the wheel path, CIR treated pavement rut depths were 83% more severe than control pavement rut depths. Also, CIR pavement rut depths were 60% to 183% more severe on uphill grades >=4% than downhill grades >=4%. IRI values were comparable between the CIR pavement and the control. As a result of this research ConnDOT has established a goal to select four new construction projects, one from each District on low volume roadways, to receive CIR treatment of the base. The Department's Pavement Management section will determine which pavements are most suitable for this application, following the 2005 guidelines developed by the pavement preservation work group.

Full-text: http://docs.trb.org/01139964.pdf

Related to rolling density:
Title: A Non Destructive Gauge for Measurement of Density and Moisture of Recycled Materials
Authors: Gamache, Ronald; Pluta, Sarah
Source: 2005 International Symposium on Pavement Recycling
Abstract: TransTech Systems has developed a spectroscopic impedance measurement instrument suitable for determination of the properties of engineering materials that contain water. The first prototype device using this technology was designed to measure the density and moisture content of engineering materials, such as soil. The method uses the Maxwell- Wagner effect to develop a signature that can be used to quantify and separate the effects of the constituents in a mixture. The prototype Soil Quality Indicator (SQI) has been designed for use in typical utility trenches, bellholes, and keyholes. Existing electromagnetic sensor technologies (ground penetrating radar and time domain reflectometry) cannot separate the effects of moisture and salinity on the measurement of density. The accuracy of sensors that measure soil density or stiffness from the surface will be affected by the volumetric density profile. TransTech is developing impedance tomography to measure volumetric properties such as density or moisture profile of engineering materials. In the process of field evaluation of the SQI prototype, TransTech had the opportunity to test the gauge on cold-inplace recycled (CIR) asphalt and recycled concrete. Currently, these materials cannot be easily measured with nuclear gauges due to non-water hydrogen present in some additives and recycling agents. SQI data on CIR asphalt shows insensitivity to surface water (introduced during the rolling process) without need for compensation. In addition, the bulk water present in the CIR binder and milled pavement exhibits a Maxwell-Wagner response that can be used to compensate density readings for the presence of moisture. In many cases, the information content in the impedance spectrum is encoded in subtle shifts in the Maxwell-Wagner response, therefore requiring very high measurement resolution and accuracy. TransTech has advanced the state-of-the-art in wideband impedance measurement by producing an accurate, sensitive, low-cost electronics package suitable for use in field instrumentation.
Full-text requires Inter-library Loan (ILL) - contact MnDOT Library if needed

Title: Cold in-place recycling literature review and preliminary mixture design procedure
Authors: Salomon, Atenea; Newcomb, David
Source: Minnesota DOT, LRRB, University of Minnesota (2000)
Abstract: This research report summarizes the results of a project to assist in the development of a mix design procedure for partial depth cold in-place recycling (CIR) mixtures. An asphalt pavement rehabilitation method, CIR involves mixing reclaimed asphalt pavement (RAP), water, and a recycling agent in place and without heat. During the construction of partial depth cold in-place recycling, one type of CIR, milling is done at depths of 50 to 100 mm (2 to 4 in.) with the resulting layer frequently used as
base course. In this project, researchers mixed RAP from Trunk Highways 23, 59, and 71, and County State Aid Highway 5 with emulsions CSS-1, HFMS-2s, and HRMS-2p. After preparing specimens with a gyratory compactor and Marshall hammers, researchers tested the specimens for bulk specific gravity, maximum specific gravity, and air voids. In addition, **indirect tensile strength tests were used to evaluate the effects of changes in curing periods and compactive effort on CIR mixtures**. Researchers concluded that the asphalt content in the RAP affects the emulsion to be added in the CIR mixture; that emulsion HFMS-2p resulted in the lowest overall voids; and that the gyratory compactor produced the best specimens for testing and evaluation.

Full-text: [http://dotapp7.dot.state.mn.us/research/pdf/200021.pdf](http://dotapp7.dot.state.mn.us/research/pdf/200021.pdf)

**Title:** Current Practice of Cold In-Place Recycling of Asphalt Pavements  
**Authors:** Wood, Leonard; White, Thomas; Nelson, Thomas  
**Source:** Transportation Research Record, no. 1178, pp. 31-37 (1988)  
**Abstract:** As part of a study to develop standard design procedures and specifications for cold in-place recycling of asphalt pavements, a literature review and a survey of state and local highway agencies and contractors were performed. The results indicate a diversity of cold in-place recycling use, design, and construction. Cold in-place construction can be divided into three distinct types: (a) a stabilization process, (b) a single unit miller or mixer process, and (c) a process using full construction trains. Several promising recycling agents have been identified and some guidelines for compaction and curing have been developed. Specific mix design procedures and structural design show great variation among users, however, and no single method can be recommended. Cold in-place recycling construction involves milling or pulverizing the existing pavement, reduction in size, mixing, laydown, and compaction. Most agencies then apply a fog seal, surface treatment, or thin overlay as a wearing surface. Overall, cold in-place recycling has shown satisfactory performance and considerable cost savings over conventional overlays. Further evaluation of procedures, specifications, and performance is recommended, however, to standardize this practice.


**Non-U.S. Results**

Related to ground penetrating radar (GPR)  
**Title:** Detailed Evaluation of Select CIR Projects in Alberta  
**Authors:** Sharma, V; Johnston, A; McMillan, C; Khan, A; Grell, D  
**Source:** Proceedings of the 62nd Annual Conference of the Canadian Technical Asphalt Association (2017)  
Alberta Transportation has completed rehabilitation of a number of highway sections using Cold In-place Recycling (CIR) and Full Depth Reclamation (FDR) over the years. In order to better understand the mechanism responsible for the formation of transverse cracks (specifically to see if transverse cracks are reflecting from the underlying pavement) and the susceptibility of the recycled material to moisture induced damage, Alberta Transportation retained Tetra Tech to undertake pavement inspections and analysis of selected projects rehabilitated using CIR and FDR. A total of five highway segments rehabilitated with CIR and one highway segment rehabilitated with FDR were included in the study. The study included a review of background information, visual crack mapping, pavement inspection using Ground Penetrating Radar, asphalt pavement coring, determination of moisture content in the CIR portion of the cores, and visual assessment of the cores to identify the progression and type of cracks. The key objectives were to investigate the performance of the pavements rehabilitated with CIR in terms of transverse crack formation and moisture susceptibility. This paper discusses the completed evaluation and findings from the study and further expands on Alberta Transportation’s experience with CIR, as presented at the 2016 CTAA Conference.

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**Title:** Non-Destructive Testing of Cold In-Place Recycled Materials at Very Young Age  
**Authors:** Lecuru, Q; Carter, A; Ethier, Y  
**Source:** Proceedings of the 61st Annual Conference of the Canadian Technical Asphalt Association (2016)  
**Abstract:** Nowadays, Cold In-place Recycling (CIR) is a pavement rehabilitation technique that is used extensively in Canada. Pavements rehabilitated with CIR are opened to traffic very soon after
compaction. The characteristics of this very young material are unknown and complicated to test with the usual laboratory methods. The objective of this study is to test the characteristics of CIR materials at a very young age. In order to do so, two non-destructive methods were utilized. First, a Light Weight Deflectometer (LWD) was used, then shear wave propagation tests (Vs) were performed on the same mixes that were left to cure at room temperature over a long period. In this paper, the development of a new shear wave propagation test apparatus is explained followed by the results and the analysis of the experimental plan. The method developed to measure shear wave velocity (Vs), which can be transformed into elastic modulus, is simple, rapid, and cost effective. The results show that it's possible to evaluate the change of behavior of CIR materials with time with Vs, and that those results can be linked with the modulus back-calculated from the LWD tests.

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Related to ground penetrating radar (GPR)
Title: Early-Life Performance of Cold-in-Place Pavement Recycling with Foamed Asphalt Technique
Authors: Loizos, Andreas; Papavasiliou, Vasilis; Plati, Christina
Source: Transportation Research Record, no. 2005, pp. 36-43 (Jan. 2007)
Abstract: The cold-in-place recycling technique with foamed asphalt stabilization was used to rehabilitate a severely damaged, heavily trafficked highway, part of the Trans European Network. Lack of experience, at least as far as the performance of the aforementioned technique for heavy-duty pavements was concerned, was the main reason for the Greek Ministry of Public Works to undertake a field experiment incorporating semirigid and flexible pavements. To achieve this goal, a comprehensive monitoring and data analysis research study was performed; it concentrated on the falling weight deflectometer as a major tool for the in situ evaluation of early-life performance of the recycled pavement. In addition, as-built roughness and ground-penetrating radar measurements, accomplished with in situ material coring and related laboratory tests, were performed. The roughness data analysis raised several issues concerning the construction of the recycled layer. According to the deflection analysis, an improvement in the recycled pavement structural condition was observed during the early life. The foamed asphalt material of the semirigid pavement proved to be stiffer than that of the flexible pavement. Furthermore, significant differences between pavement design parameters and related in situ characteristics were obtained through the strain response analysis.


Title: Influence of accelerated curing on cold recycling
Authors: Fiedler, J; Kominek, Z; Racek, I; Vacin, O
Source: Proceedings of the 4th Eurasphalt and Eurobitume Congress (May 2008); European Asphalt Pavement Association
Abstract: This work is a continuation of one part of the research program SCORE, which was dedicated to cold recycling using asphalt emulsions. The goal here was to investigate curing time and conditions at elevated temperatures and lower humidity. The mixes tested had higher cement content than in SCORE in order to satisfy the Czech specification for cold recycling. A comparative test program was conducted among Eurovia Services and Czech Technical University laboratories with the emphasis of curing practice that will not damage mixes with rather high cement content. Samples were compacted by 5 MPa of static compression. Specimens were evaluated using the indirect tension test and stiffness modulus. Results indicated that it is possible to speed up process of curing by temperature increase and humidity decrease 3 days after processing for mixes with Portland cement content up to 3% and with appropriate emulsion and water content. The conclusions of this study are compared with the literature and similar research.

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Title: Influence of Accelerated Curing on Cold In-Place Recycling
Authors: Carter, A; Fiedler, J; Kominek, Z; Vacin, O; Barberi, A; Perraton, D
Source: Proceedings of the 52nd Annual Conference of the Canadian Technical Asphalt Association (Nov. 2007)
Abstract: This work is a continuation of the SCORE research program, which was dedicated to cold recycling using asphalt emulsions. The goal here was to investigate curing time and conditions at elevated temperatures and lower humidity in order to predict material behaviour after several years in service. A comparative test program was conducted among Eurovia Services and Czech Technical University laboratories with the emphasis of curing practices that would lead to the improvement of mechanical properties. Different curing times (from 1 hour to 28 days), at different temperature (18 and 60
deg C) with different moisture contents were also tested at the Ecole de technologie superieure. The European samples were compacted using 5 MPa of static compression and they were evaluated using the indirect tension and stiffness modulus testing. The Canadian samples were compacted with a Marshall hammer and tested in Marshall stability. Samples were also tested in rutting resistance and in thermal cracking resistance. Conclusions of this study were compared with the literature and similar research. An increase in moisture content results in a decrease of stability and modulus. An accelerated cure of 24 hours at 60 deg C seems to give good stability. The CIR materials show good rutting resistance and good thermal cracking resistance.

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Title: Curing of Cold in Place Recycled Asphalt Mixtures: Toward a Standard Test Method
Authors: Mostafa, A; Isgor, B; Abd El Halim, A; Goodman, S; Lane, B
Source: Proceedings of the 51st Annual Conference of the Canadian Technical Asphalt Association (Nov. 2006)
Abstract: With escalating oil prices, pavement recycling is an attractive choice for road maintenance since it allows considerable savings as compared to new construction. It also mitigates environmental impacts, reduces the use of virgin materials, and minimizes transportation of materials off-site. Recycling of asphalt pavement is based on two different techniques: Hot In-place Recycling (HIR) and Cold In-place Recycling (CIR). Although CIR has significant advantages, the main disadvantage concerns the assessment of the CIR before being overlaid. Traditionally, assessment of the CIR mixes has been done on the basis of moisture content and compaction measurements - both of which require destructive and time-consuming testing. There is a need to develop a reliable test method that rapidly and accurately identifies when the CIR is ready for overlay. To date, a feasibility study has indicated that simple, non-destructive tests can monitor the changes in the moisture content of the mixes and that these measurements can be interpreted to give information about the curing of CIR. A more comprehensive experimental program will be carried out to calibrate the developed test method. This paper presents an overview of the problem, summarizes the major findings of the feasibility study, and describes the proposed methodology.

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Title: Investigation of the Curing Properties of Cold-In-Place Recycled Asphalt Pavements
Authors: Isgor, O Burkan; Halim, Abd El; Mostafa, Abdelzaher
Source: Ontario Ministry of Transportation (June 2006)
Abstract: The main goal of this study was to ascertain the most appropriate laboratory tests to utilize to evaluate the curing of bitumen-emulsion treated materials. It is important to ensure that laboratory tests can characterize the field curing properties of cold-in-place pavement mixes, in a reliable manner. Static compression tests reliably predicted curing of cold-in-place mixes in the laboratory.

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