MPC-530
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Project Title:
Screening of South Dakota Asphalt Mixes for Moisture Damage using Conventional and Innovative Approaches

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Research Needs:
Moisture-induced damage (also called stripping) is a major distress in asphalt pavements. The loss of strength and durability in asphalt mixes due to the reduction in bond strength between aggregate and binder in presence of moisture is called moisture-induced damage [1-5]. South Dakota Department of Transportation (SDDOT) and other DOTs in Region 8 spend millions of dollars annually to combat stripping problem. Also, with increased use of warm mix asphalt (WMA) and mixes containing reclaimed asphalt pavement (RAP), polymer-modified asphalt binders (PMA), and anti-stripping agent (ASA), evaluation of stripping potential of asphalt mixes has become particularly important. For example, there are state- and national-level concerns over the moisture-induced damage potential of WMA mixes. This is due to presence of water in mixes as a result of water injection in foamed WMA mixes and incomplete drying of aggregates at lower WMA mixing and compaction temperatures. Also, some aggregates, upon their incorporation in an asphalt pavement containing some binder sources and/or WMA additives, may lead to a higher moisture-induced damage potential. Therefore, there is an immediate need for evaluation of the effects of different additives and asphalt binder and aggregate sources on pavements' moisture-induced damage potential. As a response to this need, the present study is proposed to evaluate the moisture-induced damage potential of asphalt mixes used in Region 8. More specifically, effects of RAP, WMA, ASA, PMA, and sources of binders and aggregates on moisture-induced damage potential of mixes commonly used by asphalt contractors in South Dakota will be evaluated. Additionally, in an effort to highlight the problematic mixes, aggregates and asphalt binders from recent projects that have shown stripping in the field will also be identified and tested in collaboration with SDDOT.

The moisture-induced damage potential of an asphalt mix is generally evaluated using the indirect tensile strength ratio (TSR), which is the ratio between conditioned and unconditioned indirect tensile strengths (ITS) or from the stripping inflection point (SIP) in the Hamburg wheel tracking (HWT) test, in accordance with the AASHTO T 283 and AASHTO T 324 test methods, respectively. Although these tests are widely used by DOTs for screening asphalt mixes, they do not address the failure mechanisms governing the stripping of asphalt pavements, which may cause some misjudgments in prediction of the moisture-induced damage potential. Also, the currently-used approaches for analyzing TSR results are empirical in nature, which do not reflect the field performance of a mix. A number of laboratory studies show that some mixes with relatively low TSR values performed well when tested using the HWT, and vice versa [6,7]. This type of observations raises questions about the reliability of TSR and HWT tests for screening moisture-induced damage potential at the mix design stage. From a mechanistic viewpoint, it is imperative to evaluate the bond strength between asphalt binder and aggregate, to assess stripping. A good adhesion bonding is essential to ensure good resistance to moisture-induced damage and fatigue [1, 3, 7-10]. In absence of a reliable and quick method for screening of mixes for moisture damage, introducing a simple and quick test and analysis method with a strong mechanistic basis becomes very critical. Therefore, proposing a simple and reliable test method based on the fracture mechanics for screening the moisture-induced damage potential of asphalt mixes was defined as another objective of the present study. The results of this study will be compiled in a database and are expected to help the DOT and asphalt industry in selection of asphalt binders and aggregates to maximize the durability of the asphalt pavements. Therefore, in addition to immediate implementation, the proposed study involves a high degree of novelty.

Research Objectives:

The specific objectives of the proposed project are as follows:

1. Identification and collection of asphalt binder samples, aggregates, WMA mixes, ASA, and lime from pertinent sources;
2. Develop an easy-to-use database consisted of bonding strengths and compatibility between aggregates and asphalt binders containing PMA, RAP, WMA additive(s), and ASA;
3. Conduct semi-circular bend (SCB) tests on plant-produced and laboratory-compacted samples before and after moisture conditioning them;
4. Conduct ITS tests on plant-produced and laboratory-compacted samples before and after moisture-conditioning them and analyze the results using conventional (TSR) and fracture energy-based methods (SCB and ITS) [11];
5. Conduct binder bond strength (BBS) tests on asphalt-aggregate samples before and after moisture conditioning them. Tests will be conducted on binders containing different additives, namely RAP, WMA additive(s), and ASA and aggregates collected from different sources in South Dakota;
6. Compare/rank/correlate SCB, TSR (analyzed using both conventional and proposed methods), test results with the BBS data;
7. Evaluate the SCB test's suitability as a simple test method for screening of asphalt mixes for moisture-induced damage;
8. Conduct a technology transfer workshop for personnel of DOT and private sector.

Research Methods:

Asphalt mixes, aggregates, additives and asphalt binders for this study will be collected from asphalt mix producers in South Dakota in consultation with SDDOT. The ITS tests will be performed on conditioned and unconditioned samples as per AASHTO T 283 test method. The collected ITS data will be analyzed using two methods: (i) by determining the conventional TSR values in accordance with AASHTO T 283 standard; and (ii) by using a novel method proposed for analyzing the ITS data applying energy concepts and fracture energy theory [11]. Also, semi-circular bend (SCB) tests will be conducted on dry and moisture-conditioned samples and the results will be analyzed using the fracture energy approach (Figure 1). The critical strain energy release rate, called the critical value of J-integral or Jc will also be calculated. The SCB test results, Jc ratio of conditioned to unconditioned sets, will be used to characterize the moisture-induced damage potential of asphalt mixes based on the fracture mechanics concept. The work flow and testing plan for asphalt mixes proposed in the present study are summarized in Figure 2. Furthermore, the asphalt

Figure 1 A photographic view of SCB test

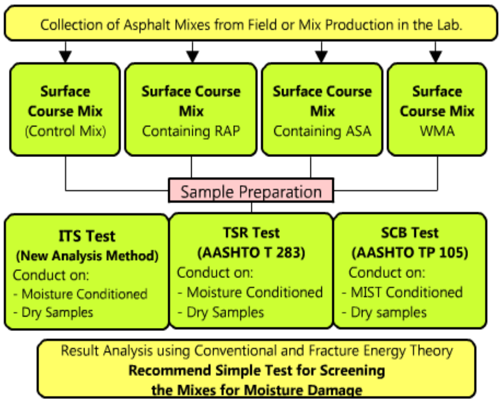

Figure 2 Work flow and plan for testing mixes

binder-aggregate bond strength tests will be conducted on conditioned and unconditioned asphalt-aggregate samples by means of the bitumen bond strength (BBS) test, in accordance with AASHTO TP-XX-11 standard method [12]. The BBS test method quantifies the tensile force needed to remove a pullout stub adhered to an aggregate surface with asphalt binder. Asphalt-aggregate samples will be prepared at controlled temperature, humidity, and moisture conditions. After sample conditioning, the pullout stub will be loaded with a tensile force by a pneumatic loading system until failure using an ASTM D 4145 Type IV adhesion tester [13]. The pullout tension at failure will be measured, recorded, and used to describe the adhesive properties and compatibility between aggregates and asphalt binders in presence of water. The work flow and testing plan for BBS tests proposed in the present study are summarized in Figure 2. Finally, the SCB and BBS test results will be analyzed and compared with those of ITS test analyzed by applying the two aforementioned approaches (methods i and ii). The results will be summarized and used to quantify bond, assess compatibility between aggregates and asphalt binders, potential failure mechanisms (cohesive, adhesive), and moisture-induced damage potential of commonly-used asphalt mixes in Region 8. Effects of RAP, WMA, ASA, and polymer-modification of binders will be examined and included in the study's database. Also, the feasibility of the proposed version of SCB test for evaluation of moisture damage in asphalt mixes will be examined after analyzing the test results. The SCB test may be recommended as an alternate method for screening of mixes for moisture-induced damage. The results of this study will help the DOTs and asphalt industry to optimize selection of asphalt binders, additives and aggregates in order to maximize the durability of asphalt pavements in Region 8 and elsewhere.

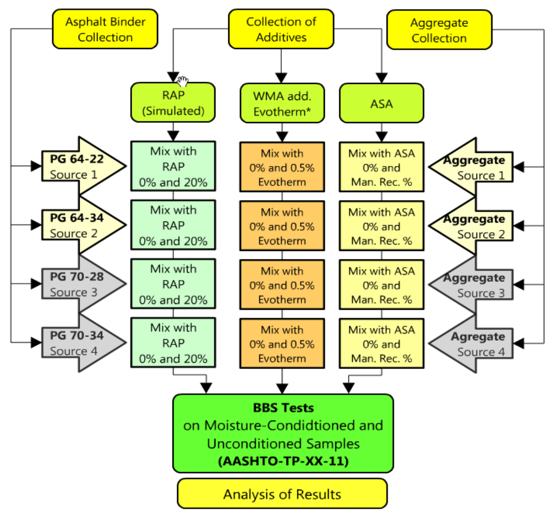

Figure 3 Work flow and plan for BBS tests

Expected Outcomes:

Specific outcomes and impacts of the proposed study are listed below:

- DOTs in Region 8 spend millions of dollars to combat stripping of asphalt pavements. Accurate screening of mixes for stripping susceptibility will avoid using stripping prone mixes in construction of new pavements and maintenance of existing pavements. Using the outcomes of this study, including the asphalt binder-aggregate compatibility database along with the new proposed testing and analyzing methods for screening asphalt mixes for moisture damage will lead to a better pavement performance and service life. Therefore, economic impacts of the proposed database are expected to be significant by any measure.
- Stripping potential of warm mix asphalt (WMA) is generally believed to be higher than hot mix asphalt (HMA), particularly when water-based foaming techniques are used in producing such mixes. Screening of WMA mixes using the newly proposed test method is expected to benefit both the asphalt industry and the DOTs because it will lead to better products and better performing pavements without any increase in production cost. In fact, water-based foaming techniques are becoming increasingly popular throughout Region 8 because they need one-time investment for plant modification and allow companies to produce mixes cheaper because of reduced fuel costs. Assuring

stripping resistant WMA mixes will have a huge impact to asphalt producers in South Dakota and other states in Region 8.

- Better screening of mixes containing RAP for stripping will increase industry confidence in using RAP in WMA, making construction more affordable (reduced cost due to RAP) and environment friendly – an important element of sustainable transportation infrastructure. It is also a major MPC goal (Economic Competitiveness).
- Use of a number of ASA with some other additives are known to result in an asphalt mix prone to moisture-induced damage. The outcomes of this study will determine the effectiveness of using ASA in asphalt mixes and their compatibility with other components in the mix.
- Recommendations and proposed draft standard on a new simple laboratory test method (SCB) and analysis technique (fracture energy-based) for moisture-induced damage will be an important advancement in screening of mixes in the design stage.
- Recommendations and proposed draft standard on a new method for analyzing the ITS results (energy-based) for moisture-induced damage will be an important outcome for this study.
- The proposed study will advance the workforce development goal of the MPC through providing important experiential learning opportunity to graduate and undergraduate student research assistants (RAs), to be appointed on this project. Experience suggests that RAs are more likely to pursue career in transportation.
- Workshops are found to be an excellent tool for technology transfer. In the proposed study, one technology transfer workshop will be conducted. We propose to conduct such workshops at SDDOT headquarter.
- The findings of this study, will be published in peer-reviewed journals and conference proceedings. Although slow, such publications can have lasting impacts on technology awareness and acceptance. Publications involving the private sector is a plus.

Relevance to Strategic Goals:
The expected outcomes of this project are directly related to the following goals: State of Good Repair and Economic Competitiveness.

Educational Benefits:
This project will provide a good learning opportunity for both graduate and undergraduate students. A graduate student (master's) will be working on this project. The results of this study will be used to provide materials for his/her thesis. Undergraduate students will also be hired on an hourly basis to work on this project. The outcomes of this study can also be used as course materials for selected lectures in the CEE 765.S01: Pavement Design course.

Work Plan:
The proposed study comprises 7 major tasks, as follows.
Task 1. Kick-off Meeting: The research team will attend the kick-off meeting with project's technical panel to discuss the scope of the study and work plan.
Task 2. Literature Review: A comprehensive literature review will be conducted during the course of this study. Sources of literature will include, but will not be limited to, regional asphalt user-producer groups' annual meetings, Asphalt Institute (AI), TRB, FHWA, NCHRP, and DOTs. Other sources such as society journals (ASCE), Western Research Institute (WRI), and NCAT will also be consulted. Moreover, national and international conferences, symposia and workshops will be reviewed. This task will be pursued throughout the duration of the project.
Task 3. Material Collection: Non-polymer-modified (PG 64-22) and polymer-modified (PG 64-34, PG 70-28 and PG 70-34) asphalt binders from a total of 4 sources, bulk RAP, Chemical WMA-additive (Evotherm), lime, ASA (ADhere HP Plus), and aggregates from different quarries (e.g., granite, gravel, rhyolite, limestone and sandstone) and asphalt mixes (surface course HMA and WMA mixes including mixes containing RAP and ASA) will be selected in close cooperation with SDDOT and industry

partner(s). RAP binder will be prepared as per methodology discussed by Ghabchi et al. [6, 7]. Materials will be collected and transported to Asphalt Lab at SDSU for testing.

Task 4. Laboratory Testing: In the current study, three tests are proposed to be conducted: two tests to evaluate the moisture-induced damage potential of the asphalt mixes using the ITS (currently-used TSR in accordance with AASHTO T 283; and ITS results analyzed using fracture energy); and one new test recommended by this study (moisture-conditioned SCB) in order to evaluate its suitability for screening the mixes for moisture-induced damage. The mixes proposed for testing will include surface course mixes with a nominal maximum aggregate size (NMAS) of 12.5 mm (0.5 in), which may contain RAP, chemical WMA, ASA, and polymer-modified binder. Mixes selected for testing will be based on SDDOT recommendations or the project panel. Figure 2 presents the work plan, test types, and mixes proposed to be tested in this project. In addition to testing asphalt mixes, BBS tests will be conducted on selected asphalt binder-aggregate samples in moisture-conditioned and non-conditioned states (AASHTO TP-XX-11). This test will allow the research team to identify asphalt binders (modified and unmodified) and aggregates which may not be compatible and cause moisture-induced damage in the future. Figure 3 presents the work plan proposed for conducting BBS tests on asphalt-aggregate systems in this project.

Task 5. Analysis of Test Results and Recommending a Simple Test Method for Screening of the Mixes for Moisture-Induced Damage: Results of BBS testing of asphalt binders and aggregates will be analyzed and compiled as a database. A mix designer will be able to select the material types, additives (RAP, WMA, ASA and polymer-modified binders) and aggregate types from the database and find out about the adhesion potential for each combination of materials. Also, the asphalt mix test results (TSR, ITS and SCB) will be analyzed using the current practice used by SDDOT and the new mechanistic approaches applied in the current project. This will result in recommending a mechanistic but simple-to-perform test method for screening of mixes for moisture-induced damage in the mix design stage.

Task 6. Outreach and Technology Transfer Initiatives: As part of implementation, it is proposed to present a workshop. Workshop will be organized at SDDOT headquarters to allow broader participation by DOT employees, NAPA members, industry, and others. Moreover, research papers will be published and presentations will be made at the TRB Annual meetings and other occasions for effective dissemination of findings of this study. Toward building a stronger transportation workforce, a major component of MPC mission and vision, we plan to blend research ideas and innovations in classroom.

Task 7. Reporting: Progress reports will be submitted to MPC, as per agency's reporting guidelines. These reports will include the overview of work done, results, observations, and problems encountered and measures undertaken to address such problems, if any. A draft final report followed by the final report will be submitted to MPC at the end of the project.

Project Cost:

Total Project Costs:	$194,089	
MPC Funds Requested:	$81,350	
Matching Funds:	$112,739	Sources of Matching Funds: Ingevity Co. and SDSU

TRB Keywords:

Moisture-induced damage potential, semi-circular bend test (SCB), indirect tensile strength (ITS), tensile strength ratio (TSR), binder bond strength (BBS) test, fracture mechanics

References:

[1] Masad, E., Zollinger, C., Bulut, R., Little, D. N., and Lytton, R. L. (2006). "Characterization of Moisture Damage Using Surface Energy and Fracture Material Properties," *Journal of the Association of Asphalt Paving Technologists*, Vol. 75, 2006, pp. 713–732.

[2] Bhasin, A., Little, D. N., Vasconcelos, K. L., and Masad, E. (2007). “Surface Free Energy to Identify Moisture Sensitivity of Materials for Asphalt Mixes,” *Transportation Research Record.*, Vol. 2001, pp. 37-45.
[3] Lu, Q. and Harvey, J.T. (2008). “Investigation of Conditions for Moisture Damage in Asphalt Concrete and Appropriate Laboratory Test Methods,” *Research Report No.: UCPRC-RR-2005-15*, California Department of Transportation, Sacramento, CA 94273-0001.
[4] Cheng, D., Little, D. N., Lytton, R. L., and Holste, J. C. (2002). “Use of Surface Free Energy of Asphalt-Aggregate System to Predict Moisture Damage Potential,” *Journal of the Association of Asphalt Paving Technologists.*, Vol. 71, pp. 59-88.
[5] King, G., Bishara, S. W., and Fager, G. (2002). “Acid/Base Chemistry for Asphalt Modification (With Discussion),” Journal of the Association of Asphalt Paving Technologists, 71.
[6] Ghabchi, R., Singh, D., and Zaman, M. (2014). “Evaluation of Moisture Susceptibility of Asphalt Mixes Containing RAP and Different Types of Aggregates and Asphalt Binders Using the Surface Free Energy Method,” Journal of Construction and Building Materials, Vol. 73, pp. 479-489.
[7] Ghabchi, R., Singh, D., Zaman, M., and Hossain, Z., (2016). “Micro-Structural Analysis of Moisture-Induced Damage Potential of Asphalt Mixes Containing RAP,” ASTM, Journal of Testing and Evaluation,44(1).
[8] Hefer, A.W., Bhasin, A., and Little, D.N. (2006). “Bitumen Surface Energy Characterization Using Contact Angle Approach,” ASCE Journal of Materials in Civil Engineering, 18(6), pp. 759-767.
[9] Wasiuddin, N. M., Zaman, M. M., and O’Rear, E. A. (2008). “Effect of Sasobit® and Aspha-Min® on Wettability and Adhesion between Asphalt Binders and Aggregates,” Transportation Research Record, No. 2051, Journal of the Transportation Research Board, Washington, D.C., pp. 80–89.
[10] Pinto, I., Kim, Y.K., and Ban, H. (2009). “Moisture Sensitivity of Hot-Mix Asphalt (HMA) Mixtures in Nebraska – Phase II,” NDOR Research Project Number: MPM-04, Nebraska Department of Roads, 1500 Highway 2, Lincoln, Nebraska 68502.
[11] Barman, M., Ghabchi, R., Singh, D., Zaman, M., and Commuri, S. (2016)“A Novel Approach for Fatigue Performance Characterization of Asphalt Mixes Using Indirect Tension Test Data” Submitted to Journal of the Transportation Research Board, Washington, D.C. (under review).
[12] ASTM D4541 - 09e1 (2009) “Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers” ASTM Volume 06.02 Paint -- Products and Applications; Protective Coatings; Pipeline Coatings.
[13] AASHTO TP-XX-11 (2011) “Test Method for Determining Asphalt Binder Bond Strength by Means of the Binder Bond Strength (BBS) Test” (under review).