Method for Determination of Optimum Emulsion Content for Emulsion-Stabilized Full-Depth Reclamation with Field Study

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ABSTRACT

Full-Depth Reclamation is a pavement rehabilitation method that has a noted history of performance in addressing pavements that show extensive structural failure and have reached the end of their functional service life. Despite widespread success with the process, there is no unified design procedure for these mixtures. This study introduces a method for determining the optimum emulsion content for Full-Depth Reclamation using asphalt emulsion on lower-volume roadways. The procedure builds off of existing literature, regional specifications, and experience with the process, while addressing the primary mode of distress observed in asphalt-stabilized granular materials. A secondary goal in developing this procedure is to utilize equipment that most basic mix design labs are currently equipped with. The engineering rationalization for the procedure is given with laboratory test data to justify the recommendations. Findings indicate that a clear optimum emulsion content exists and that the optimum emulsion content is dependent on the relative blend ratio of reclaimed pavement to base course material. The methodology was successfully applied to a field project in Wisconsin with project details given.

INTRODUCTION

Increasingly strained budgets and continually rising material costs are forcing pavement owners to reconsider their asset management strategies. The recycling and re-use of existing pavement materials has proven to be a cost-effective solution to providing the general public with safe and serviceable roadways. Full-Depth Reclamation (FDR) is one such method that has a noted history of performance in addressing pavements that show extensive structural failure and have reached the end of their functional service life. Full-Depth Reclamation reduces or eliminates the need to out-haul the existing pavement materials by pulverizing and blending the in-situ pavement and underlying base layer materials and stabilizing the blend using bituminous and/or cementitious materials. The process similarly reduces or eliminates the amount of virgin material required to be in-hauled depending on the engineering properties of the existing materials and the required performance of the stabilized layer. When properly designed and constructed, FDR layers provide a structurally sound base layer on which to construct a new pavement structure (1, 2). Additional savings may also be realized from the reduced layer thicknesses of the overlay materials; FDR layers may provide greater structural support relative to un-stabilized granular layers, thereby reducing the required thickness of the overlay materials to maintain an equivalent structural capacity (structural number concept).

Although the FDR process has been used successfully in the United States for many years, it continues to be underutilized in many regions of the country. A recent survey regarding the use of FDR indicates States that use the process frequently (more than 50 lane miles annually) appear to be distributed over several climate zones (hot-dry, cold-dry, etc.), suggesting the process can be successful over a wide range of climactic zones and traffic levels. The same synthesis study suggests that the major challenges facing the more widespread usage of the FDR process include lack of a unified mix design procedure, contractor/agency experience, and material supply (2, 3).

Full-Depth Reclamation using bituminous materials relies on either an asphalt foaming process or asphalt emulsion, and sometimes used in conjunction with other processes (usually cement). In the asphalt foaming process, a small percentage (on the order of 1-3%) of water is injected into a hot asphalt stream and converted to steam, thereby increasing the effective volume of the asphalt to the better distribute the binder and facilitate partial coating of the
pulverized materials. Asphalt emulsion is incorporated in a similar fashion, although it works on
the concept of reduced viscosity supplied by the emulsion. Both processes result in a granular
layer that can be considered non-continuously bound, meaning the aggregate particles are not
necessarily fully coated and the product behaves more as a cohesive granular layer than a
traditional flexible pavement layer (continuously bound) (4, 5). This concept is the foundation of
the methodology outlined in this paper and is elaborated on in later sections. Asphalt foam and
asphalt emulsion FDR processes have both proven to be effective when used under the
appropriate circumstances (1), although this paper deals with stabilization using asphalt
emulsion.

This study introduces the framework for a simple design procedure to evaluate asphalt
emulsion stabilized FDR materials for use on lower-volume roadways. The procedure builds off
of existing literature, regional specifications, and experience with the process. The engineering
rationalization for the procedure is given with laboratory test data to justify the
recommendations. A secondary goal in developing this procedure was to include equipment that
most contractor laboratories are already equipped with and reduce the total mix design time. A
field study in the state of Wisconsin is highlighted to support the efficacy of the procedure and
process. To maximize cost-effectiveness of the process, supplementary materials (virgin
aggregates, cement, etc.) were not used.

It should be noted that the procedure outlined in this paper does not eliminate the need for
proper engineering analysis of the existing pavement structure and may not be suitable for all
projects or materials. Similarly, the procedure does not purport to address all of the laboratory
testing required under certain circumstances or project requirements. The procedure was
developed for asphalt pavement structures with sound base layers comprised of non-plastic
granular materials and addresses the primary mode of failure in FDR mixtures. Proper structural
design and analysis taking into account anticipated traffic levels, performance needs, climate,
and materials availability should still be completed to determine if FDR is the appropriate
rehabilitation strategy for a given pavement.

BACKGROUND: MIX DESIGN METHODS
There is no unified design procedure for FDR analogous to the Superpave or Marshall
procedures used for Hot-Mix Asphalt (HMA) (2). Several proprietary, regional, or experimental
design procedures for FDR are available, yet few are used consistently. In fact, an NCHRP
agency survey on the subject of in-place recycling reports that doing nothing (i.e. do not
complete a mix design procedure prior to the work) was the most common response when asked
which mix design method was typically used (Figure 1). In states that do not have a formal
design procedure in their specifications, many require the contractor to complete and submit a
mix design. According to the survey, contractors used (in decreasing order) the Marshall,
Wirtgen, or ‘no formal design’ design procedure most commonly (3).
FIGURE 1 Agency response with regard to approach in designing recycled mixtures (3).

Unlike the Superpave design system widely used for HMA, which is based on volumetrics, many design systems for FDR rely on direct performance testing of the compacted specimens (6). This is likely due to the fact that there are no defined source or consensus aggregate properties for these mixtures, meaning the materials likely vary widely in both physical and mechanical properties. It may be impractical to specify a volumetric-based specification since the materials used for base and subgrade construction vary widely across regions. Without removing, supplementing, or otherwise modifying existing materials on a project-by-project basis, it would be difficult and cost-prohibitive to the process to specify a uniform level of density across all projects. Volumetrics in FDR mixtures may still be of importance, however. For example, the total voids in the mineral aggregate (VMA) may be important because sufficient VMA is required to provide volume for additional mixing water and water from the emulsion before the mixture cures.

Typical laboratory performance tests specified in the literature for FDR mixtures may include indirect tensile strength (i.e. diametral tensile strength), direct compressive strength, stability (resistance to plastic deformation), resilient modulus, loaded wheel testing, and moisture damage resistance (2, 6). The performance criteria specified for any one test appears to be empirically derived in most cases. In many instances, a single test temperature is specified. In addition to performance testing, typical laboratory testing involves determination of residual asphalt binder content in the existing pavement layers, existing layer thicknesses (through coring), aggregate gradations for the existing layers, determination of optimum fluids content, and recovered binder properties (3).

Many research studies focus on determination of the optimum moisture content or optimum fluids content of FDR mixtures (2). However, researchers have also reported that blends of RAP and granular materials (notably in cases of high percentages of RAP) often show inconsistent density results when comparing the standard or Modified Proctor procedures (AASHTO T 99 and AASHTO T 180, respectively) against other methods of compaction (7). The question should be raised to whether the optimum moisture content as determined with either AASHTO T 99 or T 180 can be directly translated to preparation of samples using an
alternative compaction mechanism (a gyratory compactor, for example) and including asphalt emulsion or foamed asphalt in place of a portion of mixing water.

Laboratory preparation of FDR samples is likewise variable depending on the specification followed. The most common methods of preparing laboratory specimens are the Marshall and gyratory methods. More recently, researchers have focused on gyratory compaction as it appears to be a better representation of field compaction. This is not unexpected as gyratory compaction was developed for the HMA industry to better represent typical field compaction mechanisms (3). Researchers have utilized slotted gyratory molds for emulsion based cold mix asphalt which allow for moisture to drain from the sample during compaction (2, 8). More work is needed to determine the compaction method that best represents field conditions.

From the review of the existing literature, it is clear that for a design system to be valid, it must take into account existing material properties, be based on sound engineering principles, and represent field construction practices. From a practical viewpoint, the procedure must also use tests that are repeatable, use equipment that is commonly available, and minimize time commitment.

**PROCEDURE DEVELOPMENT**

Unlike HMA, the aggregates in FDR mixtures are not intended to be fully coated. Instead, the asphalt emulsion (or asphalt foam) is dispersed among the finer aggregate particles first, creating a stabilized mortar material between the coarse aggregate particles. The coarse aggregate particles may remain partially coated or nearly uncoated. As such, FDR mixtures are considered non-continuously bound granular layers, meaning FDR layers demonstrate mechanical properties characteristic of both continuously bound asphalt layers and unbound granular layers (Figure 2) (4, 5).

![Conceptual performance characteristics of FDR materials (4).](image)

Conceptually, FDR layers are expected to maintain a similar friction angle relative to the parent materials, but offer increased cohesion (4). Applying the Mohr-Coulomb theory for
granular materials, this concept is illustrated in Figure 3. Therefore, stabilized materials can withstand a larger magnitudes of normal and shear stresses before failure. Since the asphalt in FDR mixtures is not uniformly dispersed, the FDR layer does not behave as a flexural beam (as with a continuously bound asphalt layer). Thus, the primary mode of structural failure in FDR mixtures is considered to be permanent deformation (comparable to unbound granular materials) as opposed to fatigue-based cracking coupled with permanent deformation in continuously bound materials (4, 5, 9). As such, maximizing resistance to permanent deformation should be the primary consideration in the mix design process. It should be noted that for cement-stabilized FDR materials, cracking can still occur as a primary mode of structural failure.

![Failure Envelope, Asphalt Stabilized Granular Material](image)

**FIGURE 3 Application of the Mohr-Coulomb Theory for asphalt stabilized FDR materials.**

Based on these fundamental characteristics of asphalt stabilized FDR mixtures, it is hypothesized that there exists an ‘optimum’ level of residual asphalt (directly proportional to an added emulsion percentage) unique to each FDR mixture that offers the greatest resistance to permanent deformation (mixture stability) that optimizes aggregate packing and cohesion between the granular materials. Furthermore, the maximum stability may not occur at the maximum compacted density of the mixture. Exceeding this ‘optimum’ value will result in a mixture that is more susceptible to plastic deformation as the residual asphalt binder properties begin to dominate mechanical response. By designing an FDR mixture at or slightly below this optimum value should ensure that the in-place materials are used in the most performance-efficient manner and maximize resistance to plastic deformation. Of course, the minimum level of stability required for a given project is dependent on the anticipated traffic levels, climate, and other factors, and the existing materials may need to be supplemented to meet design needs.

**Materials Selection: Proof of Concept**

The optimum stability concept was evaluated using two sets of aggregate base and reclaimed asphalt mixture materials. A typical granite aggregate base material used in central Wisconsin was selected for the first phase of this study (denoted as Base_A). The material is 100% crushed...
and is considered non-plastic. Reclaimed asphalt pavement (RAP) material was obtained from a project site in central Wisconsin (denoted as RAP_A). The aggregate material properties are shown in Table 1. Two blends of the granite base material and RAP were evaluated for proof-of-concept. The blend ratios were selected to represent typical in-place cross sections for a flexible pavement layer: a 50% Base_A / 50% RAP_A blend and a 75% Base_A / 25% RAP_A blend representing a three inch asphalt pavement layer over eight inches of base material with a nominal initial pulverization depths of six and nine inches, respectively, for the two blends.

The testing was extended to a second set of materials obtained from a field site in north-west Wisconsin to represent actual field-reclaimed materials. The purpose of including this material was twofold: to verify the concept with a different mineralogy and aggregate properties, and to include materials that have been exposed to field weathering and contamination. Cores were extracted from an existing pavement to determine average layer thickness and to obtain RAP material for laboratory testing. The base material was partially-crushed pit-run gravel. The base and core material were crushed using a laboratory scale jaw crusher to simulate pulverization. The blend ratio for this material was calculated to be 42% Base_B / 58% RAP_B based on a six inch nominal initial pulverization depth and an average existing asphalt pavement layer thickness of 3.5 inches over eight inches of base material.

<table>
<thead>
<tr>
<th>TABLE 1. Aggregate Properties</th>
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<tbody>
<tr>
<td>Sieve Size (mm)</td>
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<tr>
<td>----------------</td>
</tr>
<tr>
<td>19.0</td>
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<tr>
<td>12.5</td>
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<tr>
<td>9.5</td>
</tr>
<tr>
<td>4.75</td>
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<td>2.36</td>
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<tr>
<td>1.16</td>
</tr>
<tr>
<td>0.600</td>
</tr>
<tr>
<td>0.300</td>
</tr>
<tr>
<td>0.150</td>
</tr>
<tr>
<td>0.075</td>
</tr>
<tr>
<td>Gsb</td>
</tr>
<tr>
<td>Absorption, %</td>
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<tr>
<td>Asphalt Content, %</td>
</tr>
<tr>
<td>Fracture (1 Face), %</td>
</tr>
<tr>
<td>Sand Equivalent</td>
</tr>
</tbody>
</table>

The emulsion used in the laboratory study as well as in the field study outlined in later sections was supplied by H.G. Meigs, LLC out of Portage, Wisconsin. The emulsion is formulated as a slow-setting cationic (CSS). The emulsifier was engineered specifically for application in the FDR process. The emulsion is applied without dilution. Additional modifiers or stabilizing agents were not used in this study. The emulsion contents were selected to cover a range typically observed for FDR mixtures (1-5%); the data set for the 75% Base_A / 25% RAP_A was extended to include 6% emulsion to more clearly define the peak stability curve. The pre-
mix aggregate moisture content was kept constant at 2.5% by weight of dry aggregate based on the recommendations made in South Carolina DOT Method SC-T-99 (10).

Specimens were prepared following the procedure outlined in SCDOT SC-T-99 using a Superpave gyratory compactor. Thirty gyrations were used to compact all specimens and no post-gyration static load was applied to the specimens. Samples were extracted from the compaction molds immediately after compaction. Mixture batches were adjusted to yield specimens of 95 ± 5 mm height (approximately 3600 grams of blended aggregate). All samples were cured in a forced draft oven at 60 °C for approximately 48 hours to a substantially constant mass and cooled at room temperature for an additional 24 hours prior to testing. Resistance to permanent deformation was evaluated using a traditional Marshall loading apparatus configured to test six inch diameter specimens following ASTM D 5581. Two replicate samples were prepared at each emulsion content.

Results

Prior to stability testing, the bulk specific gravity of the mixtures was tested according to AASHTO T 166, Method A. Although it is noted that the saturated surface dry procedure may not be applicable to mixtures with high water absorption, such as mixtures with low emulsion content and/or high compacted air void content, the procedure should still give a reasonable relative approximation of the compacted density of the mixtures. The cured bulk specific gravity of the specimens is shown in Figure 4. For the range of emulsion contents tested, the bulk specific gravity of the mixtures increases uniformly with increasing emulsion content for each blend with no apparent maximum or ‘optimum’ value. The specific gravities for the BaseA-RAP_A blends appear to converge at approximately 5% added emulsion content; given the similarities in the composite gradations for each blend, this is not unexpected. Note that the 1% emulsion content samples for the 75% BaseA-25% RAP_A blend were not tested as there was a string likelihood of damage to the samples and significant loss of unbound material.

![Graph showing bulk specific gravity vs. added emulsion content](image_url)

**FIGURE 4 Cured sample bulk specific gravity.**

The sample set was tested for stability and plastic flow according to ASTM D 5581. Two testing temperatures were used: the Base_B-RAP_B blend was tested at 30 °C, while the Base_A-
RAP_A blends were tested at 38 °C, which is the alternative test temperature specified in the Marshall Design procedure for asphalt mixtures used four or more inches below the surface. The resulting data is shown in Figure 5. The stability data was fit with a second order polynomial with reasonable coefficient of determination values. The data clearly indicates that a maximum level of stability occurs for each blend and that the emulsion content required to achieve maximum stability is dependent on the source and blend ratio of materials. For the Base_A-RAP_A blends, the so-called ‘optimum’ emulsion content increases with increasing relative percentage of base material (from 3.8% to 4.1% emulsion for the 50% Base_A-50% RAP_A and 75% Base_A-25% RAP_A blends, respectively). The data supports the theory that the emulsion coats and breaks around the finest particles first; the 75% Base_A-25% RAP_A blend contains nearly 2% more uncoated P200 (dust) material relative to the 50% Base_A-50% RAP_A blend, despite having nearly identical composite gradation P200 levels. (8.50% and 8.68%, respectively). Since the P200 material in the RAP material is essentially already coated and bound, it is not free to react with the emulsion, so the blend requires less total emulsion to provide equivalent cohesion.

The stability data similarly suggests that increasing mixture density (Figure 4) does not necessarily result in increased mixture stability, namely at emulsion content levels greater than the apparent optimum. It is hypothesized that on the left side of the stability curve, increasing the emulsion content allows aggregates to orient and consolidate (increasing density) and the mixture mechanical response is dominated by inter-particle friction between aggregates and cohesion supplied by the asphalt. On the right side of the stability curve, the properties of the residual asphalt binder begin to dominate the mechanical response under load, thus allowing more plastic flow and reducing overall stability (Figure 5). This theory is supported in the HMA literature, in which the relationship between density and performance is not necessarily direct but depends on properties of the binder, aggregate, and the interaction between the two materials (11, 12).

The flow at maximum stability (Figure 5) shows a uniform increase with increasing added emulsion content. The field obtained Base_B-RAP_B blend showed the lowest flow values over the range of emulsion contents tests, which is expected given the test temperature was lower than the other two blends. The flow values for the Base_A-RAP_A blends was very similar over the range of emulsion contents tested, which is expected given the similarity of materials and stability curves.

The laboratory data set supports the hypothesis that an optimum level of added emulsion exists that offers the highest mixture stability and is unique to each FDR mixture. For the data set presented, it does not appear the maximum stability occurs at the mixture maximum compacted density level as density continues to increase with increased added emulsion. Density may be the driving factor controlling deformation resistance at emulsion contents lower than the optimum, however.
FIGURE 5 Mixture stability and flow.

FIELD STUDY

The design procedure methodology was applied to a candidate project in the state of Wisconsin in the early-fall of 2013. A summary of the project details is shown in Table 2. The candidate pavement is a two-lane rural highway with an estimated AADT of 500 vehicles and low truck traffic and was selected for rehabilitation in September of 2013. The owner opted for emulsion based FDR with a structural overlay as opposed to milling and overlay to address the structural needs of the pavement. Coring along the length of the project was conducted to determine the average and distribution of existing pavement depth as well as to procure materials for laboratory evaluation. The average existing asphalt pavement thickness was determined to be 4.25 inches with a standard deviation of 0.45 inches along the length of the project. The in-situ base material was estimated by the owner to be approximately eight inches thick. There were no indications of insufficient subgrade support (i.e. subgrade or base layer rutting) along the length of the project.
1 **TABLE 2 Field Project Details**

<table>
<thead>
<tr>
<th>Project Details</th>
<th>Average Existing Layer Thicknesses (in.)</th>
<th>Construction Details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nominal Initial</td>
</tr>
<tr>
<td>Project Location</td>
<td>Nominal Length (miles)</td>
<td>AADT</td>
</tr>
<tr>
<td>South-Central</td>
<td>1.0</td>
<td>500</td>
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</table>

The project emulsion was supplied by H.G. Meigs, LLC out of Portage, WI and was the same emulsion used in the laboratory phase of this study. After thickness measurements, the cores were crushed to simulate pulverization and relevant aggregate properties were measured. It was noted that although the base course material was considered non-plastic, the relatively low sand equivalent values indicated the presence of clay in the material. However, laboratory testing of the site materials did not indicate any incompatibilities with the project emulsion.

Due to material quantity limitations, blends at 2% and 3% emulsion content were tested. In addition, the proposed design emulsion content of 2% was tested for initial (uncured) stability according to SCDOT SC-T-99 to evaluate curing properties. The blend ratio for the laboratory testing was fixed at 30% Base and 70% RAP based on a nominal pulverization depth of six inches and an average pavement layer thickness of approximately 4.25 inches. Interestingly, the blends at 2% and 3% added emulsion met the requirements of SC-T-99 for cured stability; however, the stability data suggested that 3% emulsion was past optimum since the stability was lower than that at 2%. Given the relatively high residual asphalt content in the blend before stabilization and considering the results presented in the laboratory section suggesting that a higher residual asphalt content before stabilization may require less added emulsion, 2% was selected as the recommended dosage rate. From a practical point of view, selecting 2% provides a conservative application rate as the pavement thickness fluctuates throughout the project (i.e. the blend ratio changes slightly in the field), assuring the stability remains controlled by the aggregate properties.
Table 3 Field Study Test Results

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Base</th>
<th>RAP</th>
<th>30% Base - 70% RAP</th>
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</thead>
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<tr>
<td>19</td>
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<td>100.0</td>
<td>100.0</td>
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<td>1.16</td>
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<td>Fracture (1 Face), %</td>
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<table>
<thead>
<tr>
<th>Performance Criteria</th>
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<tr>
<td></td>
<td>2%</td>
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<tr>
<td>Cured Stability (lb)$^1$</td>
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<tr>
<td>Cured Flow (in)$^1$</td>
<td>0.296</td>
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<tr>
<td>Initial Stability (lb)$^2$</td>
<td>5,265</td>
</tr>
</tbody>
</table>

$^1$Tested at 38 °C

$^2$Tested at 25 °C

Following initial pulverization, the surface was compacted and shaped to rough profile using a grader, vibratory pad-foot roller in the initial breakdown position, a pneumatic tired roller and smooth drum roller for finishing. All roller equipment was supplied by the owner and operated in the 8-10 ton range. Where necessary a water truck was used to help achieve density of the pulverized material. The reclamation machine was then used to directly inject the asphalt emulsion to a nominal depth of four inches. Following injection, the same equipment used to initially grade and shape the profile was again used to compact the stabilized layer (Figure 6). The injection depth was determined using a total structural number design process following local specifications. The finished layer was allowed to cure for 7-10 days (with a target effective moisture content of approximately 2.5%) before being overlaid with a four inch layer of HMA placed in two lifts.

At the time of this report the finished project has been in service for approximately one year with no major distresses noted. Although this represents only short term performance relative to the life-expectancy of the pavement, the winter of 2013/2014 in Wisconsin was notably severe and along with a cool, wet spring in 2014, conditions were conducive to subgrade and base layer failure. Despite these conditions the project has not shown any signs of performance distress that can be attributed to the FDR layer.
SUMMARY OF FINDINGS & RECOMMENDATIONS

In this study, framework is introduced for determining the emulsion application rate for FDR mixtures by addressing the primary mode of failure in stabilized pavement layers. A secondary goal in developing this methodology is in utilizing equipment commonly available to most contractor laboratories and reducing mix design time. Several blends of reclaimed asphalt materials and base aggregates were tested in the laboratory to validate the concepts introduced. The findings of the laboratory study were extended to a field FDR project with apparent success. The results and analysis led to the following findings:

- A non-linear relationship between FDR mixture stability and mixture emulsion content was demonstrated in the laboratory. The findings indicate that a maximum level of stability that is dependent on the source of materials and the ratio of base material to RAP material exists. This relationship was verified for materials sampled from the field. A theory regarding the engineering rationalization for this relationship was offered.
The bulk density of FDR mixtures prepared in the lab increased uniformly with increasing emulsion content for the samples tested; the emulsion content at which the maximum stability was observed did not correspond to the maximum density in the mixture. Samples were prepared using a Superpave gyratory compactor with a 600 kPa vertical pressure and 30 gyrations of compaction effort using standard six inch sample molds. More work will be needed to determine the relationship between densities obtained in the laboratory versus those realized in field scenarios to verify this finding. Density may still be the controlling factor for performance at emulsion contents less than optimum.

The design methodology was successfully applied to a lower volume field project in Wisconsin in the summer of 2013. At the time of this report, the project does not appear to show any signs of distress related to the FDR process.

It should be noted that the testing in this report was limited to stability and may not cover the range of testing required for a given project, nor does it address the proper structural design of FDR mixtures. Nevertheless, the methodology can be applied to select the optimum emulsion content for further evaluation to help limit the possibility of permanent deformation by using the in-place materials in the most performance-effective manner. The minimum stability required (or other indicator of resistance to deformation) will also vary based on the project requirements, and may justify the use of additional stabilizing agents or supplementary aggregate materials.

The testing in this report was completed at relatively low temperatures and should be extended to higher pavement temperatures in applicable regions to determine if the same methodology applies. It is recommended that subsequent research similarly apply the methodology to the asphalt foaming processes and expand the data set to include additional emulsions and aggregate materials.

ACKNOWLEDGMENTS

The author makes the following acknowledgments in support of this study: H.G. Meigs, LLC for supplying the emulsion materials, Ken Schackelman of H.G. Meigs, LLC for coordinating the field project and supplying the accompanying photos. The help of Diane Franseen and Kim Gessner of the Asphalt Technologies Group in formulating the emulsion used in the lab and field study is also acknowledged.

REFERENCES


