Cold in-place recycling (CIR) is the on-site recycling process to a typical treatment depth of 3 to 5 inches, using a train of equipment (tanker trucks, milling machines, crushing and screening units, mixers, a paver, and rollers), an additive or combination of additives (asphalt emulsions, lime, fly ash, cement), generating and using 100% RAP, with the resulting recycled pavement usually opened to traffic at the end of the work day.

Mix Design for Cold in-Place Recycling (CIR) and Full Depth Reclamation (FDR)
Outline

• Purpose of mix design
• Sampling
• Mix design tests and emulsions
  – CIR
  – FDR
• Summary and conclusions
Purpose of Mix Design

- Determine emulsion content – provide guidance on low and high contents for construction
  - Impact on project cost
- Determine emulsion properties to meet mix and job requirements
- Look for problem materials and ways to correct for them
Sampling

- Ideally, sample locations are determined by construction and maintenance records or in-place testing (FWD, GPR)
- Samples should represent the width and length of the project to provide an overall “picture” of layer thickness values
Sampling

- Cores may identify thin areas that are insufficient for CIR or where new material could be added.
- Other testing, such as DCP, can be performed at the time of coring to evaluate the aggregate base and subgrade for strength and train support.
Sampling

- Overall quantity depends on specification and job requirements

- Bottom line – The mix design must plan on variability in materials and thicknesses
Mix design – material preparation and evaluation

• Saw-cut material that will not be used
  – Will pre-milling occur?
  – Cut bottom portion for CIR work

• Look for signs of stripping, fabric, delamination, etc.
  – Don’t leave stripped layers in place
Mix design – material preparation and evaluation

• Excessive thickness of chip seals or cold mix may give lower strength
  – High binder content

• Round aggregates may give lower strength

• Consider lime (CIR) or cement (FDR) for stripping / high fines
  – New aggregate or RAP for strength or thickness
Mix design – material preparation and evaluation

- Samples taken for extraction and gradation
- Core grinder to required gradation target(s)
  - Before grinding, look for material differences!
- Aggregate for FDR – washed gradation
- Aggregate / RAP batched to correct ratio
- Recovery of asphalt
  - Penetration and PG grading
Mix design – emulsion

- Formulated to meet mixture requirements
- Base asphalt properties, emulsifier type, and emulsifier amount

<table>
<thead>
<tr>
<th>Test</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue from distillation, % ASTM D2441</td>
<td>64.0</td>
<td>66.0</td>
</tr>
<tr>
<td>Oil distillate by distillation, % ASTM D2441</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Sieve Test, % ASTM D2441</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Penetration (TBD), 25oC, dmm ASTM D5</td>
<td>-25%</td>
<td>+25%</td>
</tr>
</tbody>
</table>
Mix design tests – CIR

CIR

- Grinder / crusher ➢ Simulate milling
- Mixer ➢ Simulate mixing
- Raveling test ➢ Adequate setting
- Marshall stability ➢ Long-term strength
- Retained strength ➢ Long-term performance
- Thermal crack ➢ Non-load cracking
Mix design – material preparation and evaluation

- Most samples are usually 100 mm in diameter
  - Raveling and IDT for thermal cracking are 150 mm in diameter
- About 1000 grams each
- Normally 3 emulsion contents
- Maximum specific gravity – 2 samples, mixed at highest emulsion content. Dryback procedure.
Mix design tests – CIR

Notes:

• The tests are based on a procedure known as an “engineered” design

• Tests and specs can vary agency to agency

• There are others tests and methods that have worked well (gradation or volumetric based), such as in NY
Mix design – grinder or crusher to simulate milling

- Miniature lab milling machine or jaw crusher to simulate expected field gradations
- Will need to experiment with crusher settings to determine how to obtain target gradations
Mix design – target gradations

- CIR targets are similar to below curve
- Usually two target gradations per mix design
Mix design – mixing

- Use a mechanical mixer to better simulate mixing that occurs in field equipment
- Modified bucket mixer
Mix design – mixing

- Percentages are on a dry weight basis of RAP
- Mix water thoroughly
  - Usually 2 to 3 percent (does not act like an aggregate – can’t determine Proctor properties)
- If lime is used, use hydrated lime, mixed with water at 35% solids
- Add emulsion and mix thoroughly
- 60 seconds of mix time for water or emulsion
Mix design – compaction and curing

- Superpave gyratory compactor
  - 30 gyrations for 100 mm specimens
  - Some specs state 20 gyrations for raveling test specs

- Cure at 60°C from 16 to 48 hours (except raveling) after compaction – usually 48h
Mix design – raveling test (ASTM D 7196)

- Indicator of emulsion breaking and setting properties
- Usually after 4 hours of curing at 50F and 50% humidity
  - California considering three temperatures
- Criteria – 2% maximum (some states 7%) after 15 minutes
  - Weigh before and after
Mix design – Marshall stability and retained stability

- 1,250 pounds Marshall stability at 40C
- 70% retained stability
  - 55 to 75% vacuum saturation (a few seconds), 23 hour soak at 25C, 1 hour soak at 40C
  - Retained strength - key performance indicator

- Some agencies use TSR
Mix design – Thermal cracking (AASHTO T-322)

- LTPPBind software – 98% reliability for closest weather station at top of CIR (overlay depth must be known)
- Not an issue for some climates
- At design emulsion content
- Three temperatures
- Two specimens are cut from one tall specimen
- Two to three samples per temperature
- Two tests on each sample – creep compliance followed by tensile strength
## Mix design – summary

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradation</td>
<td>Report</td>
</tr>
<tr>
<td>Asphalt content</td>
<td>Report</td>
</tr>
<tr>
<td>Air voids</td>
<td>Report – Typically 9 to 14%</td>
</tr>
<tr>
<td>Raveling test</td>
<td>2% maximum</td>
</tr>
<tr>
<td>Marshall stability at 40C</td>
<td>1,250 lbs min.</td>
</tr>
<tr>
<td>Retained stability</td>
<td>70% minimum</td>
</tr>
<tr>
<td>IDT thermal cracking</td>
<td>LTPPBind for weather station</td>
</tr>
<tr>
<td>Emulsion</td>
<td>In order to meet mix and project requirements</td>
</tr>
</tbody>
</table>
Mix design – typical emulsion rates

Typical emulsion quantities for CIR

- 1.5 to 3.5% or higher for engineered emulsion - CSS-1/1h (special)
- Depends on how “active” the asphalt in the RAP is
Mix design – FDR

FDR

- Grinder
  - Simulate milling

- High shear mixer
  - Simulate mixing

- Cohesion test
  - Early strength

- ITS
  - Long-term strength

- Retained strength
  - Long-term perf.

- Modulus
  - Structural

- Thermal crack
  - Non-load cracking
Mix design tests – FDR

Notes:

• The tests are based on a procedure known as an “engineered” design

• Tests and specs can vary agency to agency

• There are others tests and methods that have worked well (gradation or volumetric based)
Mix design – grinder or crusher to simulate milling

- Miniature lab milling machine or jaw crusher to simulate expected field gradations
- Target gradation (only one)
Mix design – preparation of materials

- Blend RAP and aggregate base to expected ratios
- Perform Modified Proctor for OMC – Method C, 6 inch mold

- Water for mixing:
  - 60 to 75% of OMC if SE \( \leq 30 \)
  - 45 to 65% of OMC if SE > 30 (blend of RAP and aggregate)
  - Lower end of range for western / arid climates
Mix design – material preparation and evaluation

- Samples with emulsion are usually 150 mm in diameter
- About 2700 grams each
- Normally 4 emulsion contents
- Maximum specific gravity – 2 samples, mixed at highest emulsion content. Dryback procedure.
  - Cannot use aluminum pressure vessel if it contains cement
Mix design – mixing for FDR

• Use a high shear mixer to better simulate mixing that occurs in field equipment
Mix design – mixing

- Percentages are on a dry weight basis of material
- Mix water thoroughly
  - Based on OMC
  - Can back down water for increasing emulsion as long as within required range
- If a dry additive is needed, cement (Type 1) is used. Type C fly ash is also possible.
  - Mixed into RAP / aggregate blend before water
  - Range of 1% to 1.5% (usually 1%)
- Add emulsion and mix thoroughly
- 60 seconds of mix time for water or emulsion
Mix design – curing before compaction

- Loose specimens cured individually in plastic containers of 4 to 7 inches (100 to 180 mm) height and 6 inches (150 mm) diameter
- Specimens cured at 40°C for 30 (± 3) minutes. No further mixing or aeration shall occur during this time
Mix design – compaction and curing

- Superpave gyratory compactor
  - 30 gyrations
  - 10 second hold after 30 gyrations

- Cure at 40°C for 72 hours (except cohesiometer) after compaction
Mix design – cohesiometer for FDR

- Indicator of emulsion breaking and setting properties
- Cured 60 minutes at 25°C
- Two tests per specimen
Mix design – indirect tensile strength and retained strength for FDR

- 40 psi ITS at 25C
- 25 psi retained strength after vacuum saturation and moisture conditioning
  - Key performance indicator
Mix design – Thermal cracking (AASHTO T-322)

- **Modulus before IDT at 25C**
- LTPPBind software – 98% reliability for closest weather station at top of CIR (overlay depth must be known)
- Not an issue for some climates
- At design emulsion content
- Three temperatures; two specimens are cut from one tall specimen; two to three samples per temperature
- Two tests on each sample – creep compliance followed by tensile strength
# Mix design – summary

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<tr>
<td>Cohesiometer test</td>
<td>150 or 175 min. (depends on fines)</td>
</tr>
<tr>
<td>ITS at 25C</td>
<td>40 psi minimum</td>
</tr>
<tr>
<td>Retained ITS</td>
<td>25 psi minimum</td>
</tr>
<tr>
<td>Resilient Modulus at 25C</td>
<td>150,000 psi minimum</td>
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Mix design – typical emulsion rates

Typical emulsion quantities for FDR

• 2.0 to 5.5% or higher for engineered emulsion - CSS-1/1h (special)
• Depends on amount of aggregate base and quantity / quality of fines
Mix design – summary

- HMA industry tests have been adapted for CIR and FDR mix designs (except raveling or cohesion)
- CIR or FDR acts like a slightly lower modulus HMA material
Questions?