# Thermal Cracking and the Use of Disk-Shaped Compact Tension Test (DCT) Performance Testing

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OMRR Research Seminar

10/20/2015

UMD
University of Minnesota Duluth
Driven to Discover

Minnesota Department of Transportation

# *Why do we need to specify Low Temperature Cracking performance of asphalt mix?*

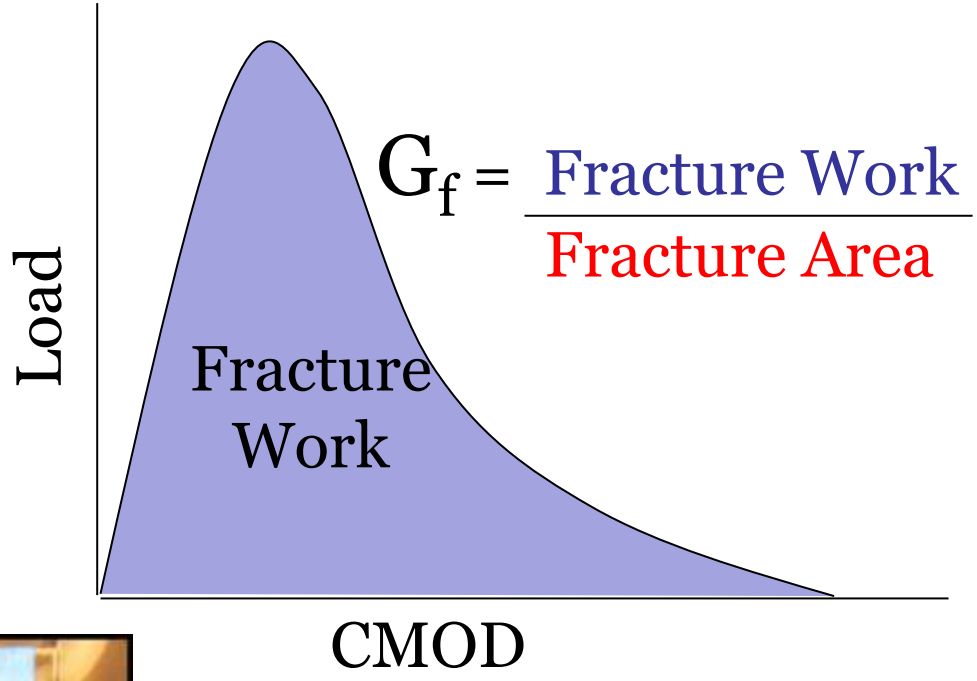
- Binder is important, but does not completely control material behavior:
  - Aggregate/mastic effects on mixture creep/fracture properties
  - Effects of RAP, RAS, WMA, and other additives
  - Mixture volumetrics and aggregate effects – voids, aggregate size and gradation
  - Plant/field aging

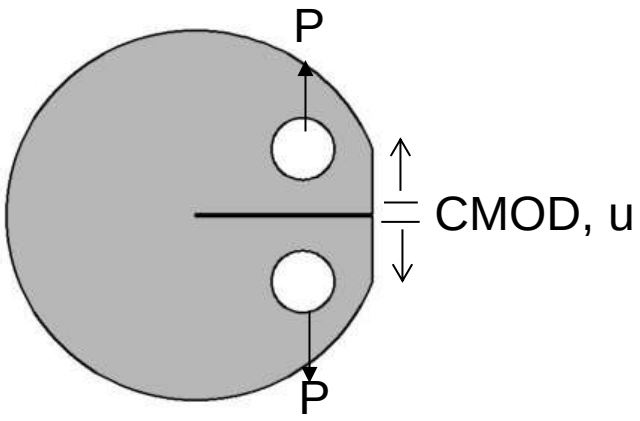
# *What is the DCT Test?*

- Disk-Shaped Compact Tension Test (DCT)
- Low-temperature performance test for asphalt mixtures
- Determines fracture energy ($G_f$), measured in $J/m^2$
  - Measure of a mixture's resistance to cracking
- Recommended by low-temperature cracking pooled fund study to measure thermal fracture resistance

# *Disk-Shaped Compact Tension, DCT Test*

- ASTM D7313-13
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD = 0.017mm/s (~1.0-mm/min)
- Measurements:
  - CMOD
  - Load



# *LTC Performance Specifications*

- Based on traffic levels

| **Limits** | **Project Criticality / Traffic Level** | | |
|---|---|---|---|
| | High (> 30M ESALs) | Medium (10 – 30M ESALs) | Low (< 10M ESALs) |
| DCT Fracture Energy ($J/m^2$) | 690 | 460 | 400 |
| IlliTC Cracking Prediction (m/km) | < 4 | < 64 | Not required |

Marasteanu et al., 2012

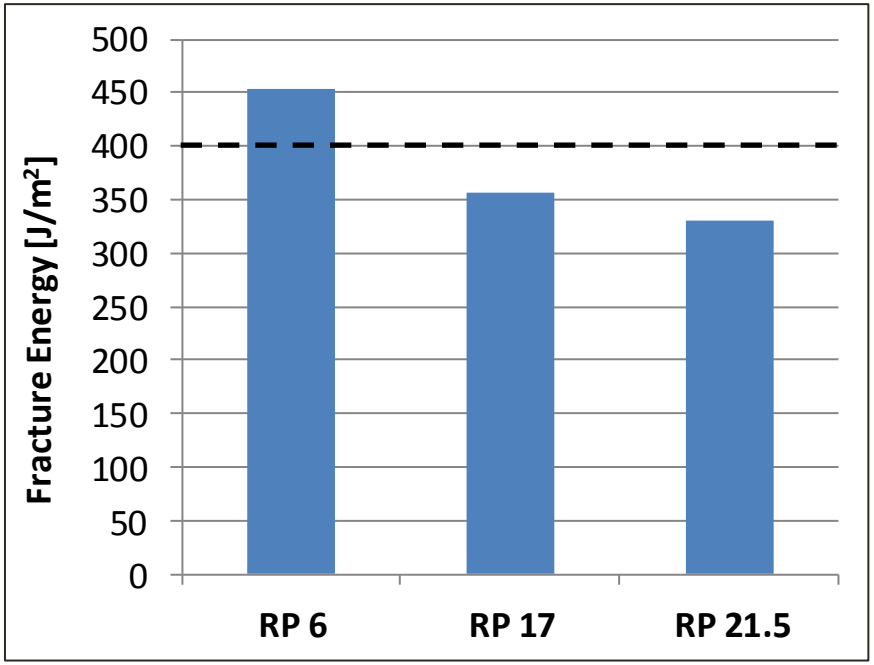
# Results for TH371 Sections

Field Cores (TH371)

RP6: Good performing section (2005 construction)

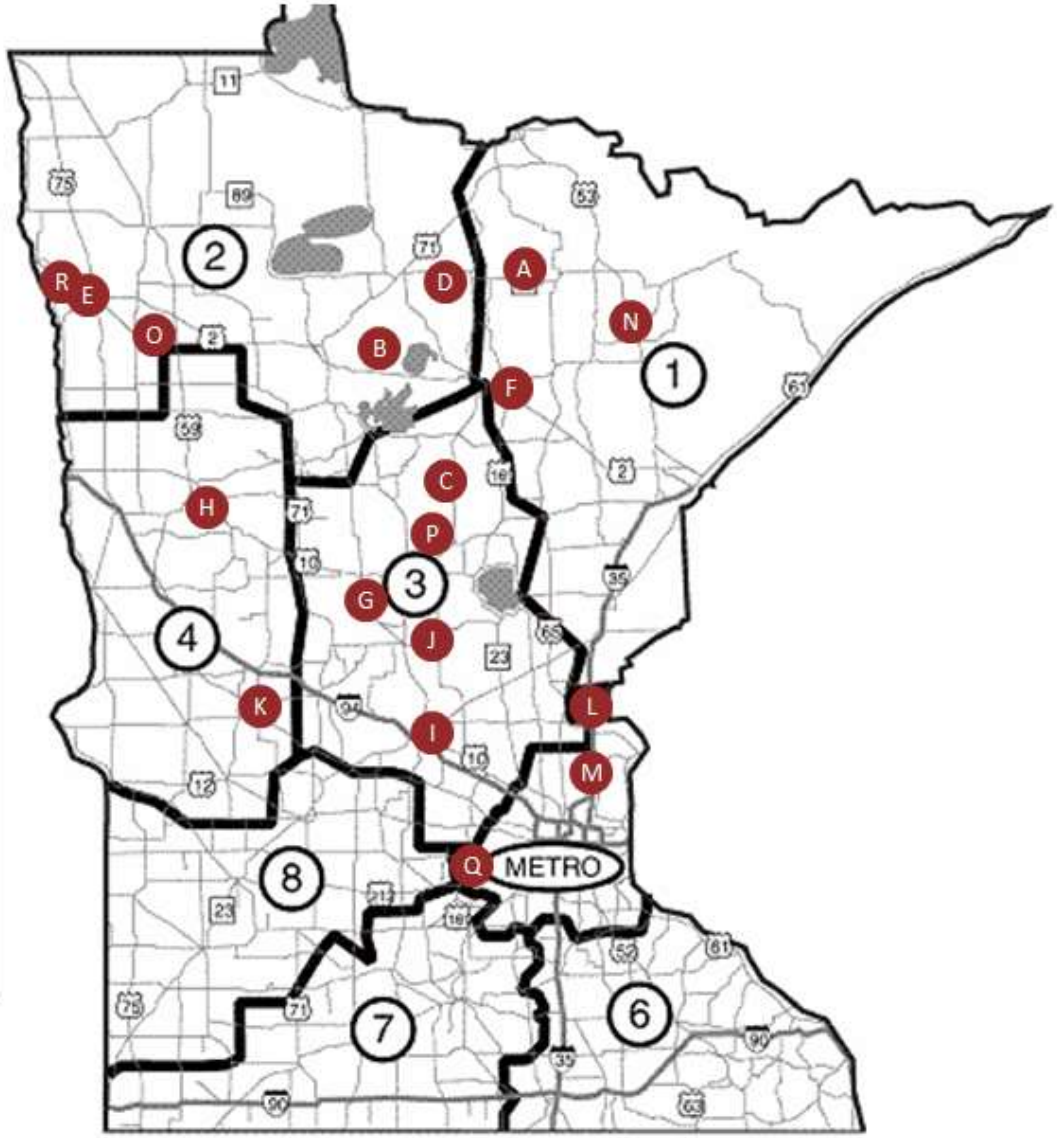
RP17/21.5: Poor performing section (2004 construction)

| RP | North Bound Crack Count | South Bound Crack Count | Fracture Energy [J/m$^2$] |
|---|---|---|---|
| 6 | 3 | 4 | 453.44 |
| 17 | 12 | 8 | 356.18 |
| 21.5 | 10 | 57 | 330.59 |

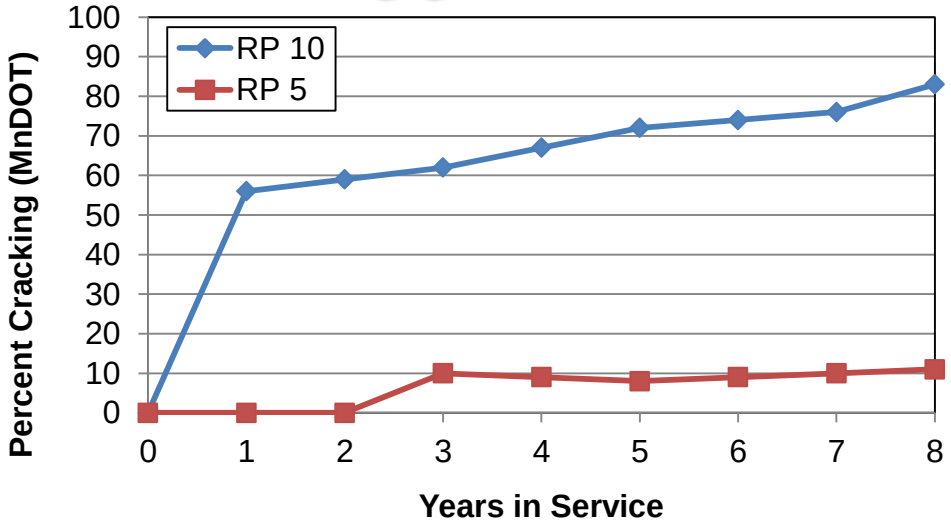


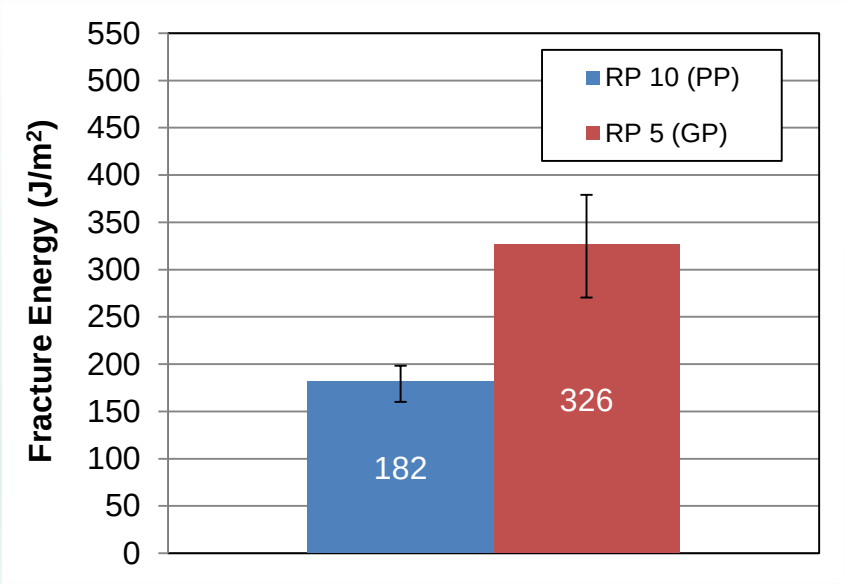
# *Field Core Testing*

| | |
|---|---|
| A = TH 1 | (Dist. 1) |
| B = TH 2 | (Dist. 2) |
| C = TH 6 | (Dist. 3) |
| D = TH 6 | (Dist. 2) |
| E = TH 9 | (Dist. 2) |
| F = CSAH 10 | (Dist. 1) |
| G = TH 10 | (Dist. 3) |
| H = TH 10 | (Dist. 4) |
| I = TH 25 | (Dist. 3) |
| J = TH 27 | (Dist. 3) |
| K = TH 28 | (Dist. 4) |
| L = CSAH 30 | (Metro) |
| M = I-35 | (Metro) |
| N = TH 53 | (Dist. 1) |
| O = TH 113 | (Dist. 2) |
| P = TH 210 | (Dist. 3) |
| Q = TH 212 | (Metro) |
| R = TH 220 | (Dist. 2) |

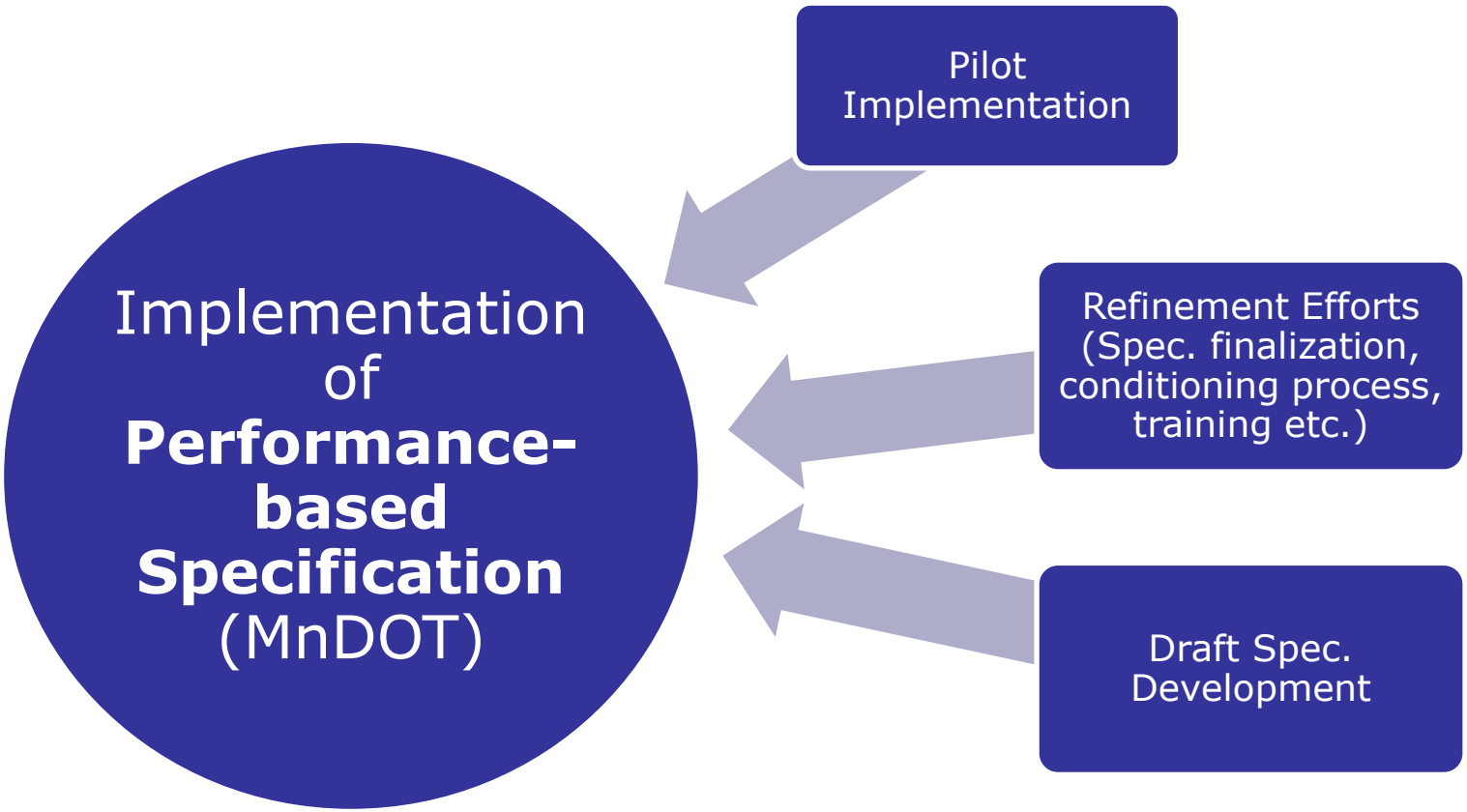


# Field Cracking Performance vs. Fracture Energy



# *Refinement and Implementation of Specification*



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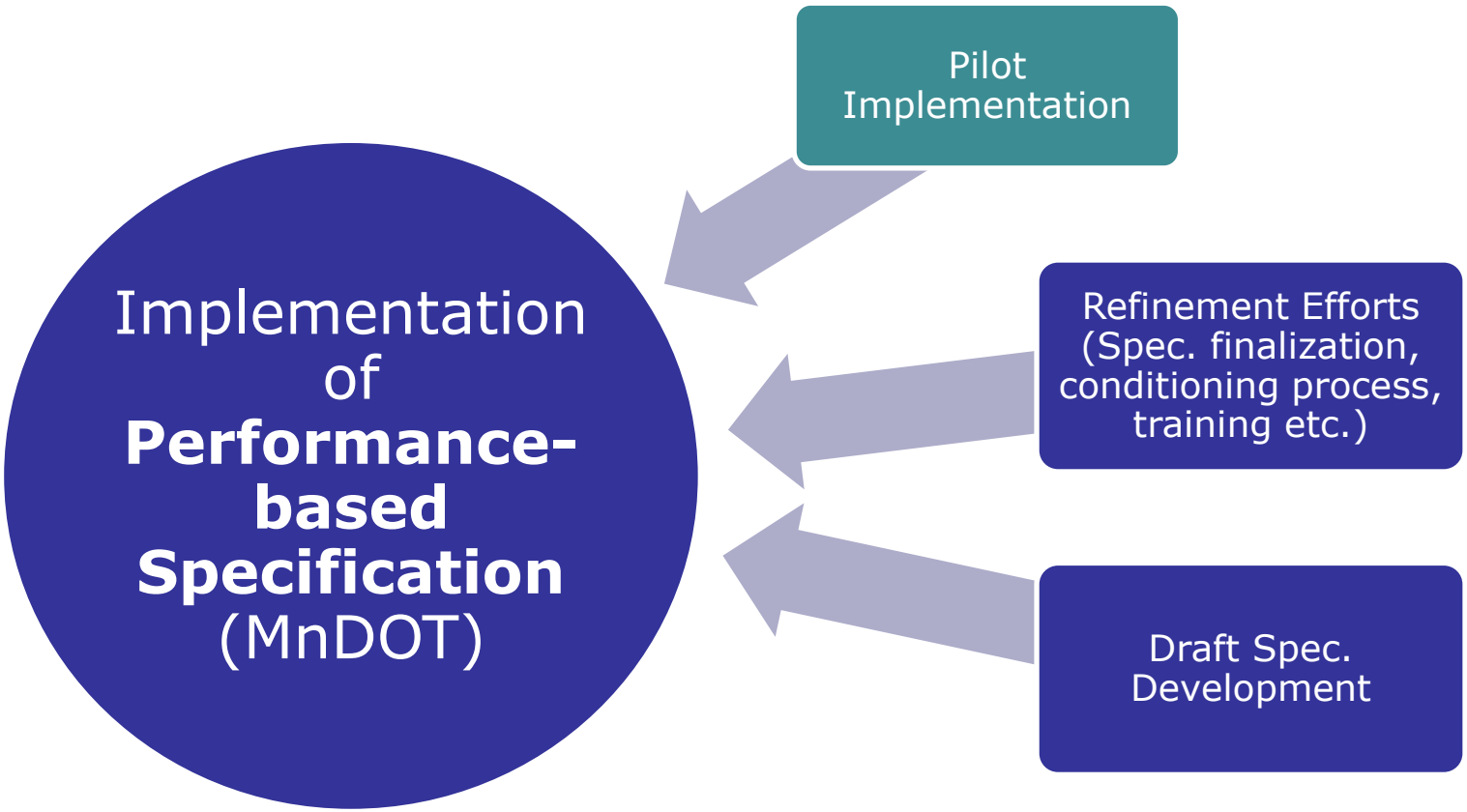
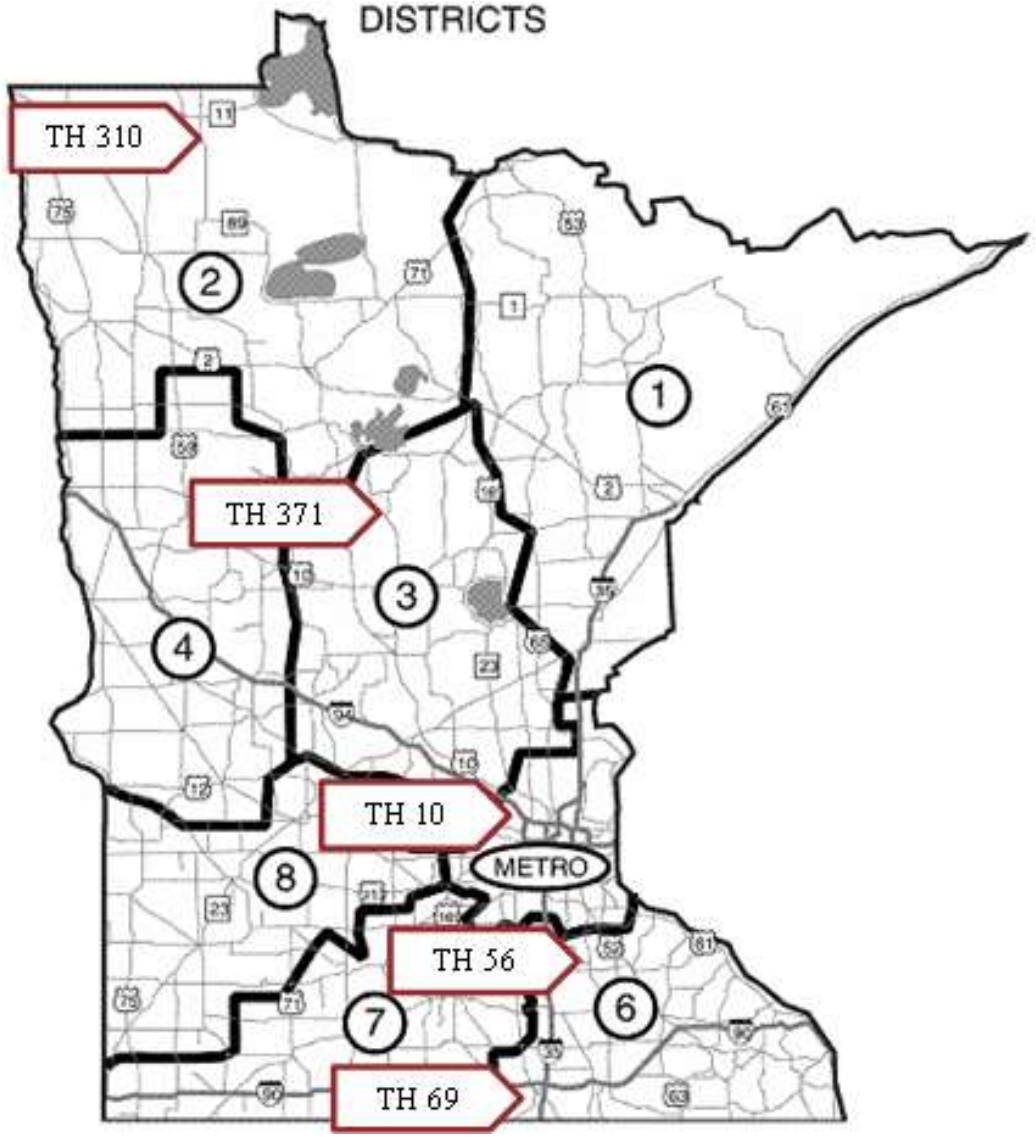
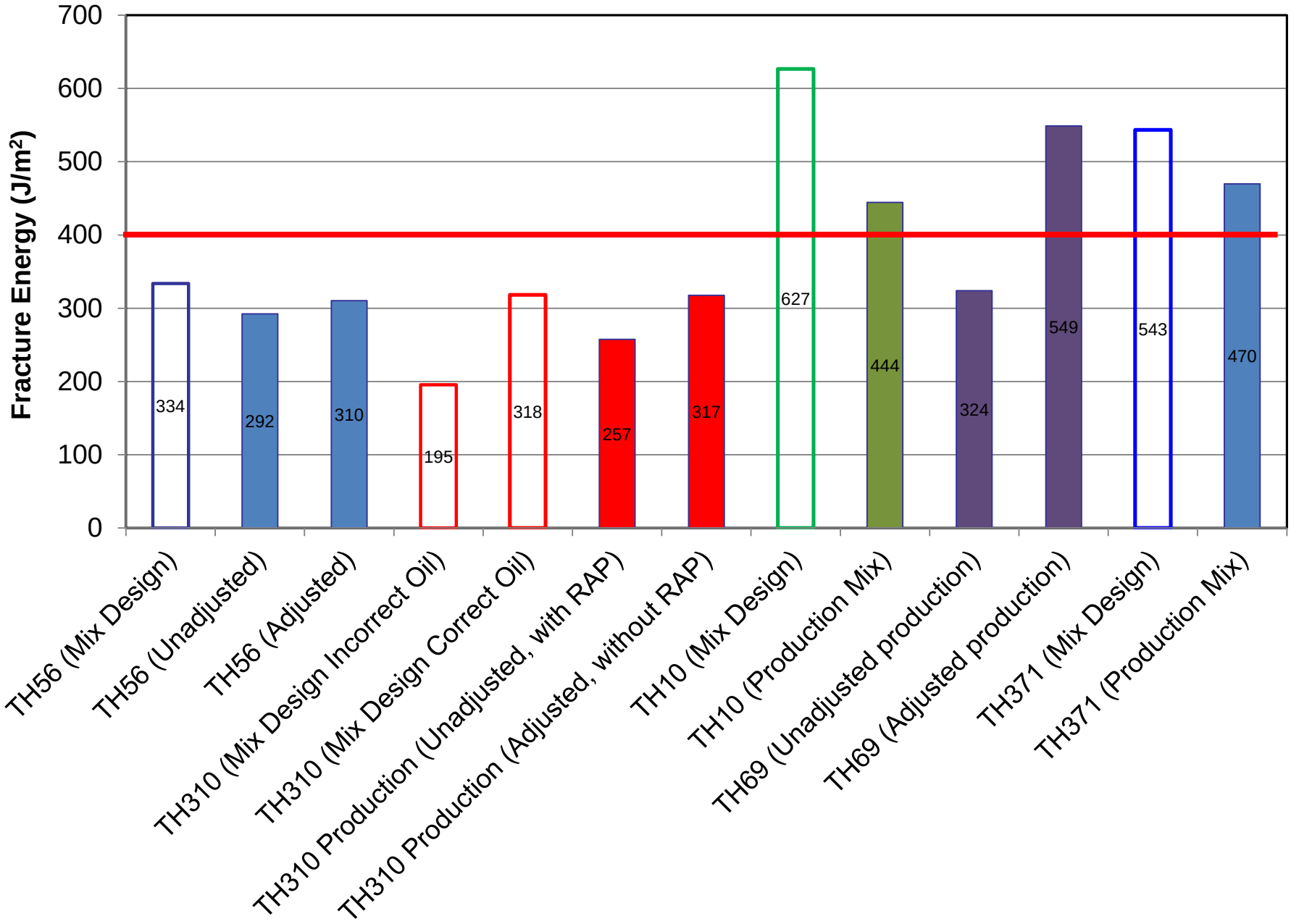


# Projects

- Variety of climates, binders, construction
  - D2 – TH 310, FDR + Overlay, PG 58-34
  - D3 – TH 371, Reconstruct, PG 64-34
  - Metro – TH 10, Mill & Overlay, PG 64-28
  - D6 – TH 56, SFDR + Overlay, PG 58-34
  - D6 – TH 69, Mill & Overlay, PG 58-28




Fracture Energy (J/m²)
700
600
500
400
300
200
100
0
334
292
310
195
318
257
317
627
444
324
549
543
470
TH56 (Mix Design)
TH56 (Unadjusted)
TH56 (Adjusted)
TH310 (Mix Design Incorrect Oil)
TH310 (Mix Design Correct Oil)
TH310 Production (Unadjusted, with RAP)
TH310 Production (Adjusted, without RAP)
TH10 (Mix Design)
TH10 (Production Mix)
TH69 (Unadjusted production)
TH69 (Adjusted production)
TH371 (Mix Design)
TH371 (Production Mix)

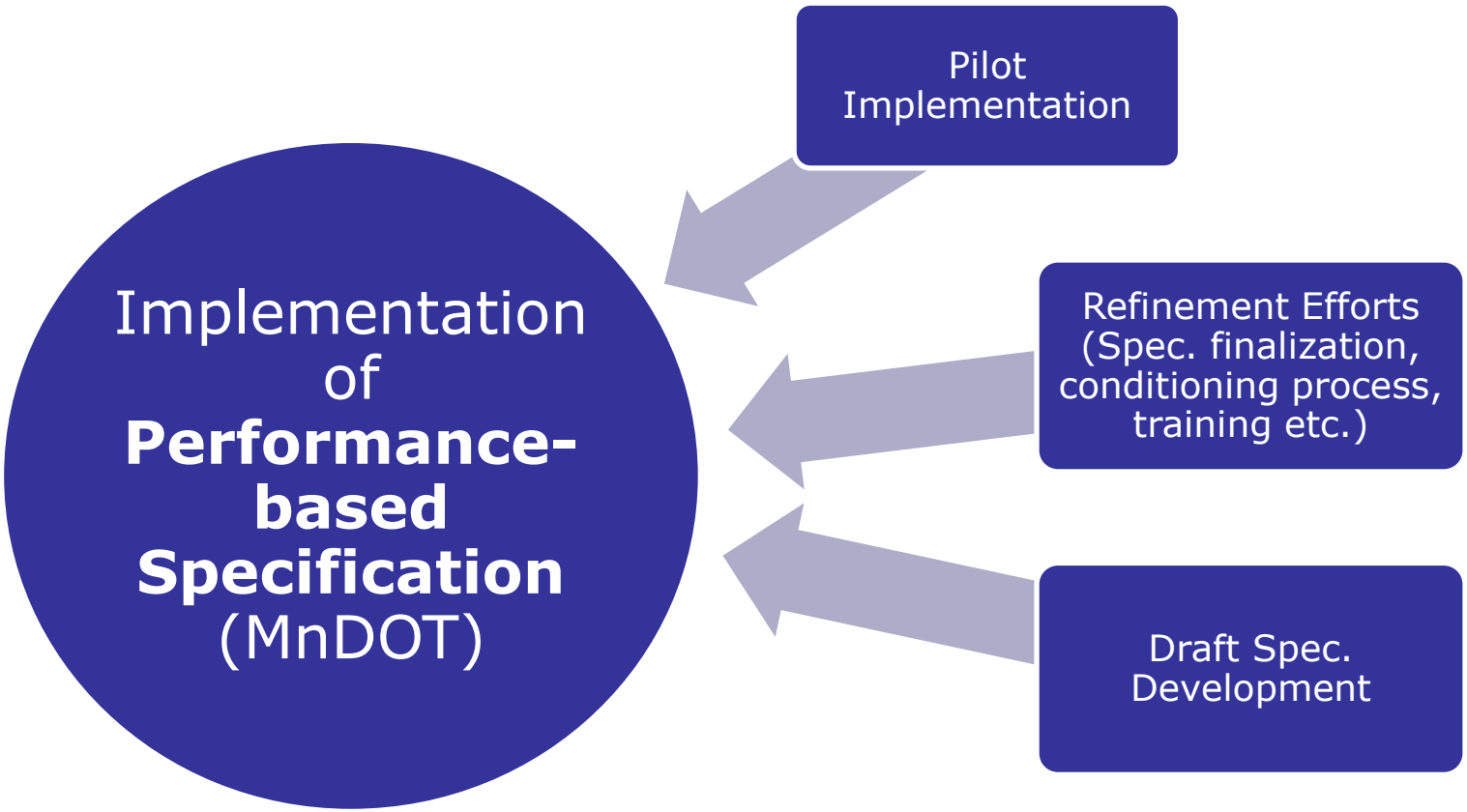
# *Summary*

- 2 projects (TH10 and TH371) passed at mix design
  - Both Level 4 designs (Higher amounts of crushed agg.)
  - Both polymer modified
- 3 failed at mix design
  - TH 69, 58-28, 30% RAP, 324 J/m$^2$
    - *Adj. 58-34, 20% RAP, 549 J/m$^2$*
  - TH 56, 58-34, 20 % RAP, 292 J/m$^2$
    - *Adj. + 0.1% new AC, 310 J/m$^2$*
  - TH 310, 58-34, 20% RAP, 257 J/m$^2$
    - *Adj. 58-34, 0% RAP, 317 J/m$^2$*
    - *Old oil in mix design, 195 J/m$^2$*
- Need to make sure that same materials are used for mix design and production (esp. binder)

# *Possible Mixture Adjustments*

- Binder grade
  - Reduce low PG (-34 vs -28)
- Different modifier or supplier
- Aggregate source and crushing
  - Granite/taconite instead of limestone
- Aggregate Gradation
  - Finer gradation
  - Increase binder content

# *Refinement and Implementation of Specification*



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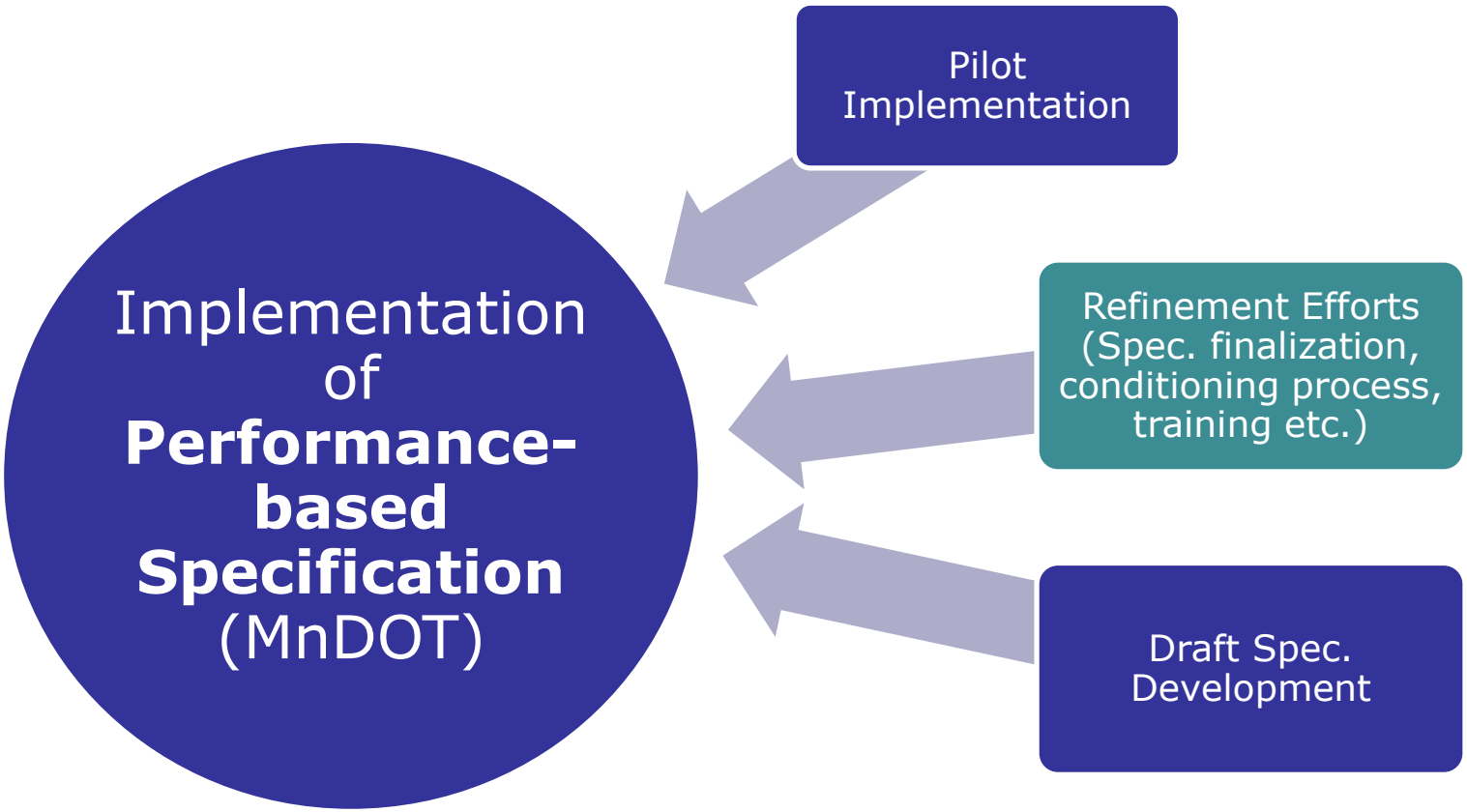
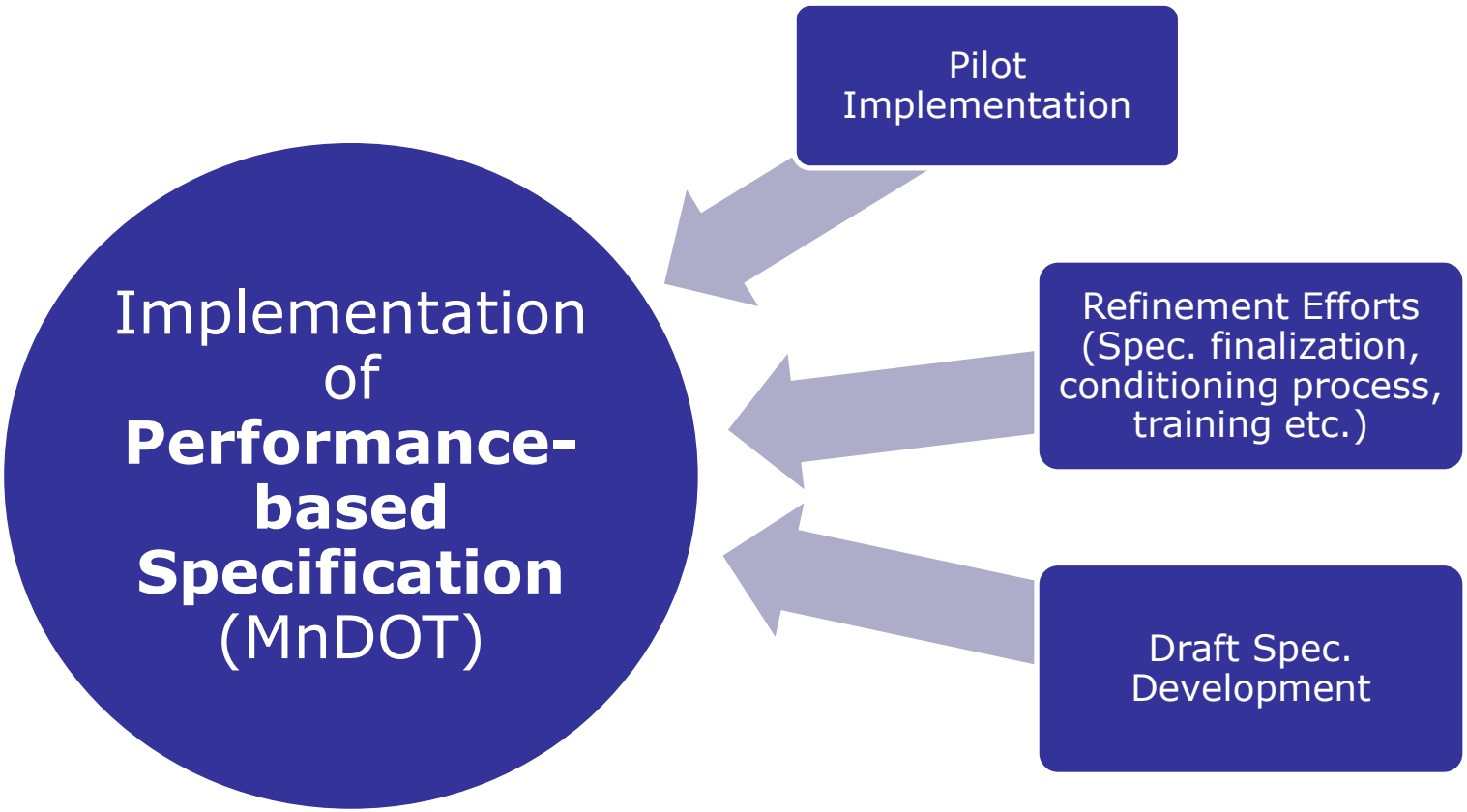


# *MnDOT DCT Specifications*

- "MnDOT Modified"
  - Current version used by MnDOT
- GOAL: Improve ease, practicality and repeatability of test procedure
- Several changes/additions to ASTM specification
- Revisions made to temperature conditioning of specimens:
  - Specimens must reach test temperature within 1.5 hours.
  - Specimens must stay in conditioning chamber for a minimum of 2 hours before testing.
  - All testing must be finished within 6 hours of initial placement into conditioning chamber

# *Refinement and Implementation of Specification*



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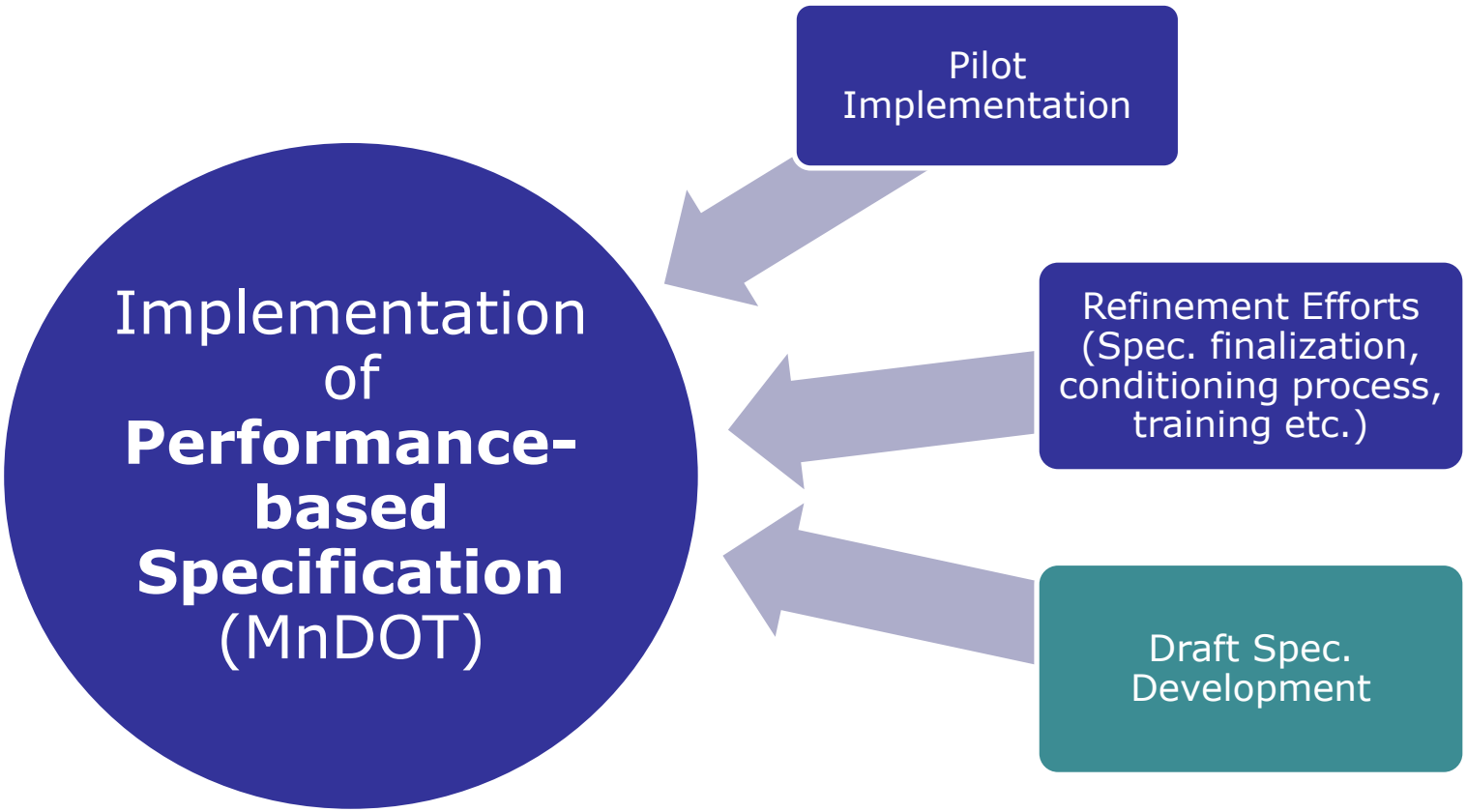
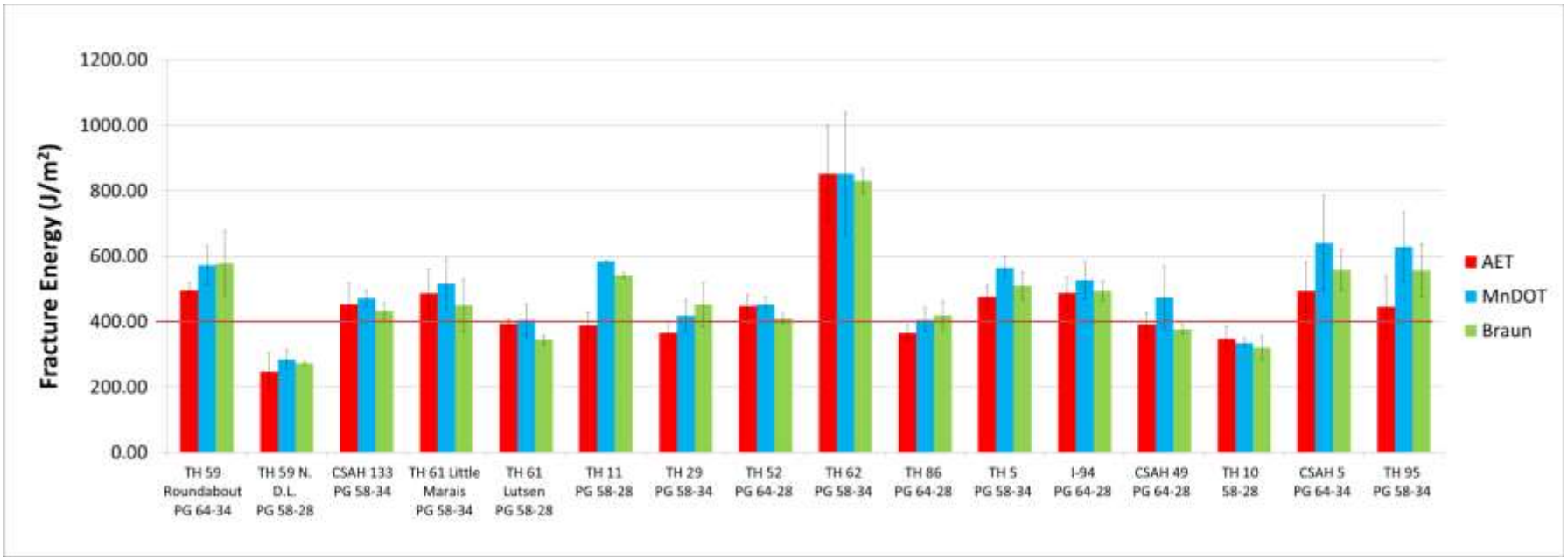


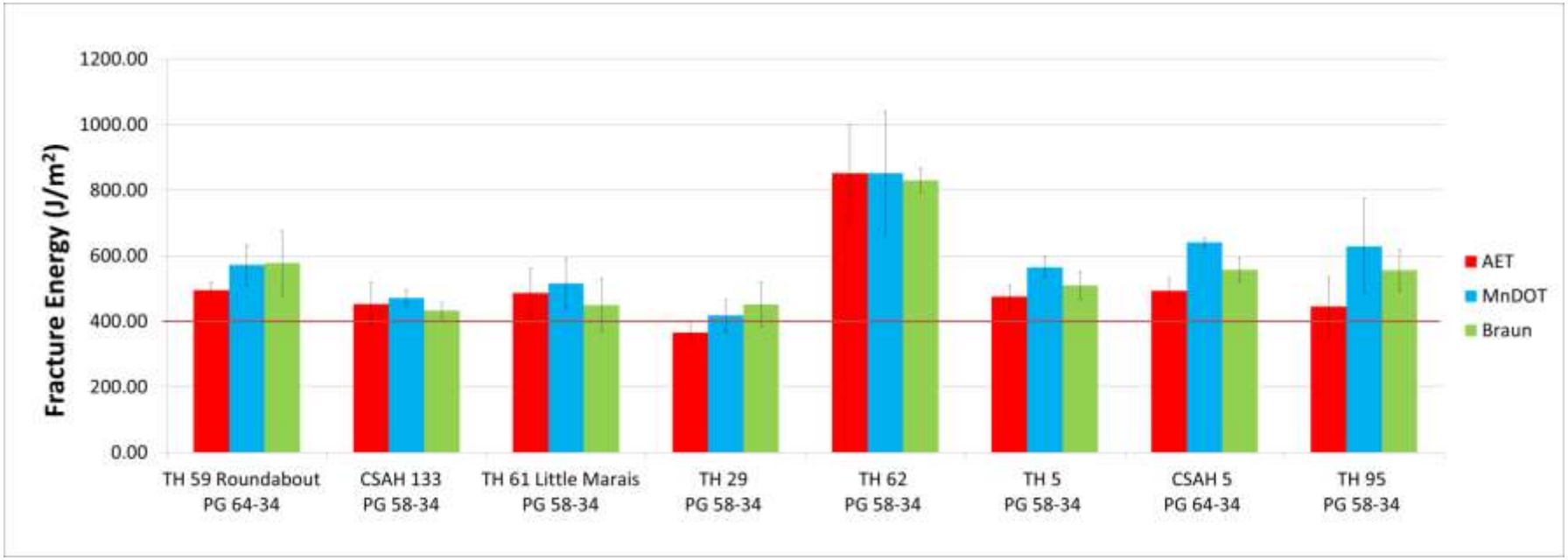
# *Round Robin Study*

- Inter-laboratory reproducibility study
  - *Samples collected during Summer/Fall 2014, with testing completed in Spring of 2015*
- 16 projects selected from around the state
- Participating labs included AET, Braun, and MnDOT

# *Average Fracture Energies: All Labs*



# *Average Fracture Energies: All Projects with XX-34 Binder*



# *Pilot DCT Provision Highlights*

- Project Selection
- Design
- Production
- Sampling

# *Project Selection*

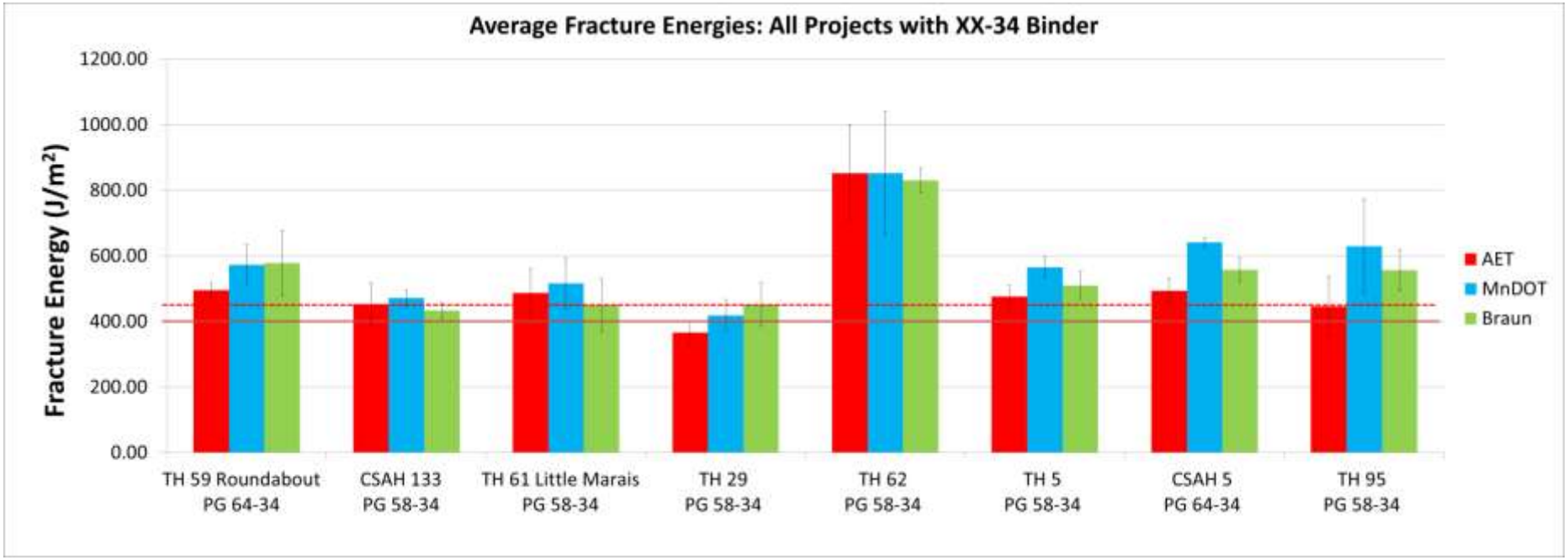
- Goal is to include DCT testing, by Special Provision, on as many projects as possible (1 from each district) in 2016.
- Include on New Construction or Reconstruction only.
- DCT requirement on Wear Mix only (top 4”)
- Minimum Wear mixture approx. 20,000 tons.
- Pre-Bid Meeting

# *Overview DCT Pilot Specification*

- Initial Mixture Design Report
  - Preliminary Mixture Design Report (MDR)
- Initial DCT Verification
  - Verify plant produced mixture meets minimum requirements
- Final Mixture Design Report
- Additional Sampling

# Mix Design Requirements

- Mix design submittal must include fracture energy results for wearing course mixture.
- Wear Course mixture only (Top 4”) PG XX-34
- Minimum Design Fracture Energy
  - Traffic Level 2 & 3 Fracture Energy 450 J/m2
  - Traffic Level 4 & 5 Fracture Energy 500 J/m2



# *Asphalt Binder Ratio Modification*

- Modified Ratio of Added Asphalt/Total Asphalt from 80% to 75%.

| **Table 2360-8**<br>**Requirements for Ratio of Added New Asphalt Binder to Total Asphalt Binder[1] min%:** | | | |
|---|---|---|---|
| Specified Asphalt Grade | Recycled Material | | |
| | RAS Only | RAS + RAP | RAP Only |
| PG XX-28, PG 52-34, PG 49-34, PG 64-22<br>Wear<br>Non-Wear | 70<br>70 | 70<br>70 | 70<br>65 |
| PG 58-34, PG 64-34, PG 70-34<br>Wear & Non-Wear | 75 | 75 | 75 |
| [1] The ratio of added new asphalt binder to total asphalt binder is calculated as (added binder/total binder) x 100 | | | |

# *Initial DCT Verification*

- Full-scale production of the wearing mixture can't begin until fracture energy of plant produced mix has been verified.
  - Verify mixture by placing mix on the project or at an alternate location.
    - *When wear mixture placed on the project, production mix will be limited to between 50 and 200 tons.*
      - *Suggestion:*
        - *With approval of Engineer substitute Wear mix (with correct asphalt grade) while placing non-Wear mixture.*
        - *No limit to production when wearing course mixture placed as non-Wear.*

# *Final MDR*

- A Final MDR, allowing full-scale production, will be issued based on successful verification of plant produced mixture.

| **Table DCT-2<br>Minimum Average Fracture Energy Mixture<br>Production Requirements for Wearing Course** | |
|---|---|
| Traffic Level/PG Grade | Fracture Energy ($J/m^2$) |
| Traffic Level 2-3/PG XX-34 | 400 |
| Traffic Level 4-5/PGXX-34 | 450 |

- Allowable Differences of Test Results

| **Table 2360-9<br>Allowable Differences between Contractor and Department Test Results** | |
|---|---|
| **Item** | **Allowable Difference** |
| DCT - Fracture Energy ($J/m^2$) | 90 |

# *Fracture Energy Testing During Production*

- Required when:
  - An aggregate proportion change for a single stockpile aggregate greater than 10% from the currently produced mixture.
  - A cumulative change on any one aggregate product exceeds 10% from the original MDR.
  - A change in added asphalt that decreases by more than 0.3% below that shown on the MDR.
  - An aggregate or RAP source is changed.
  - An increase of 5% in RAP content or 1% in RAS content.
  - A change in binder suppliers or sources.

*For each day of wear course production obtain at least five (5) full 6” x 12” cylinders for the Department. These samples will be for information only.

# *Future Efforts*

- Implementation of DCT Pilot spec on as many projects as possible (1 from each district) during the 2016 construction season
- Continue to populate the DCT results database
  - *Test and record results of specimens collected during 2015 construction season*
- Hold Pre-Bid Meeting with contractors


# *Thank you for your attention*

- Questions?

Acknowledgments:

- Bill Buttlar
- Contractors
- Producers
- Dave Van Deusen
- Shongtao Dai
- Joe Voels
- Dave Linell
- Luke Johanneck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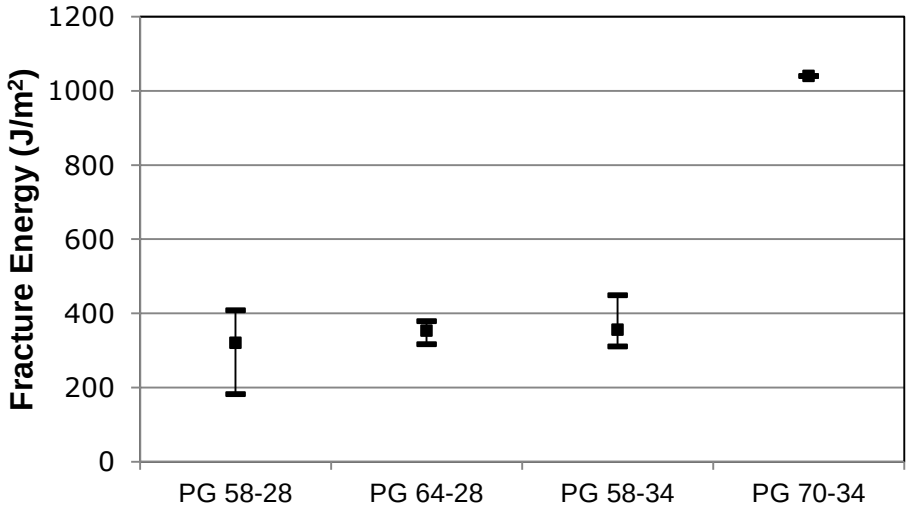
Sponsoring agencies for present work:
US Department of Transportation (FHWA)
Minnesota Department of Transportation

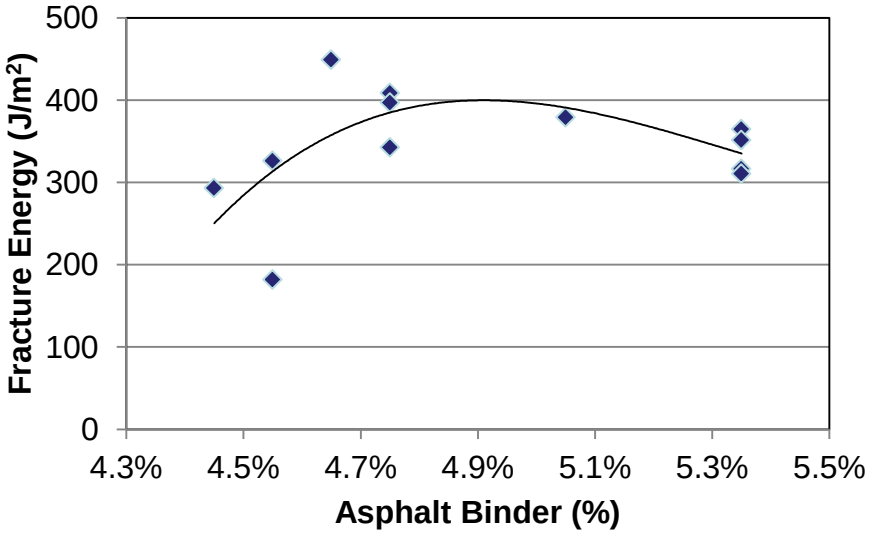
# *Appendix*

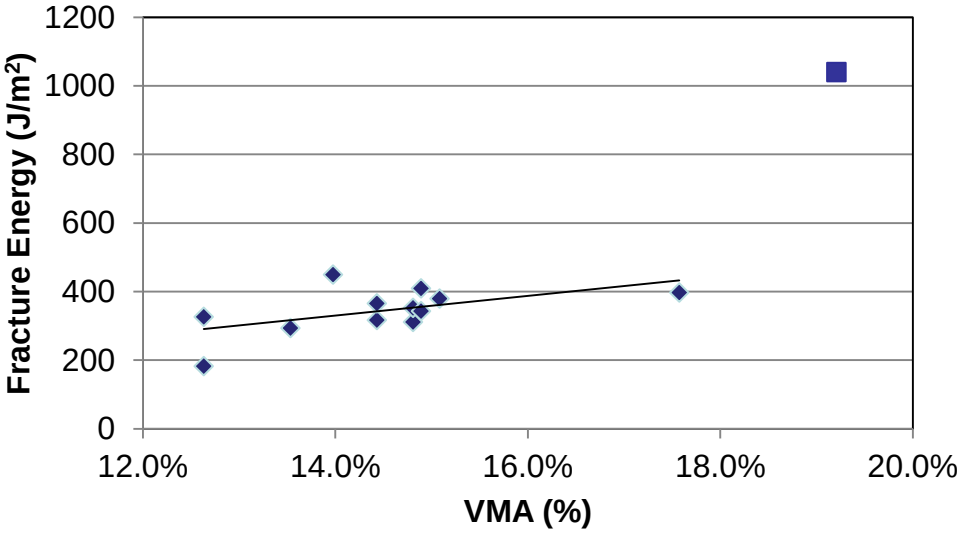
# Summary

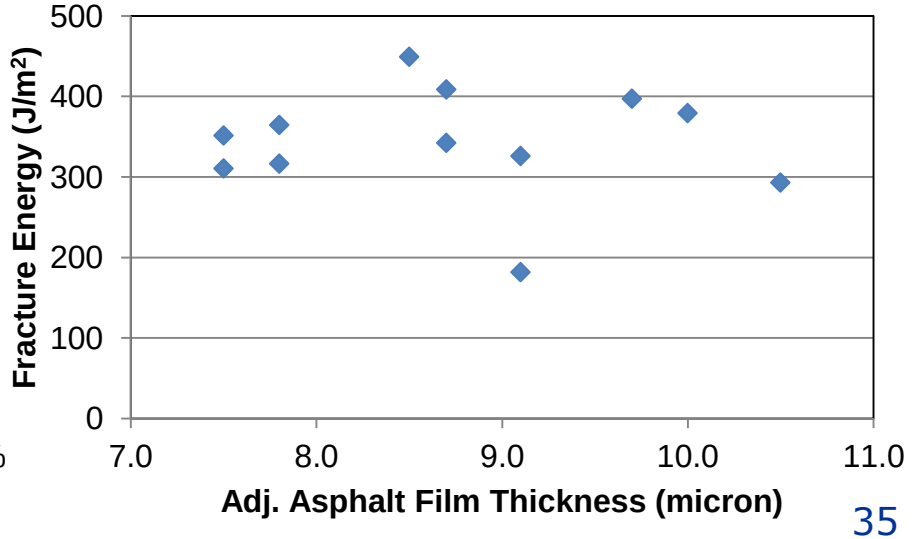
- Fracture energy has and is continuing to show high potential as cracking performance indicator
- Stay tuned:
  - 2015: Improve breadth of DCT result database
  - 2016: Continue with pilot projects
  - 2017: Goal of implementation
    - *Plan to target wear courses*
    - *New and re-construction*
    - *Possibly on thick overlays*
- Stand-alone testing equipment is available

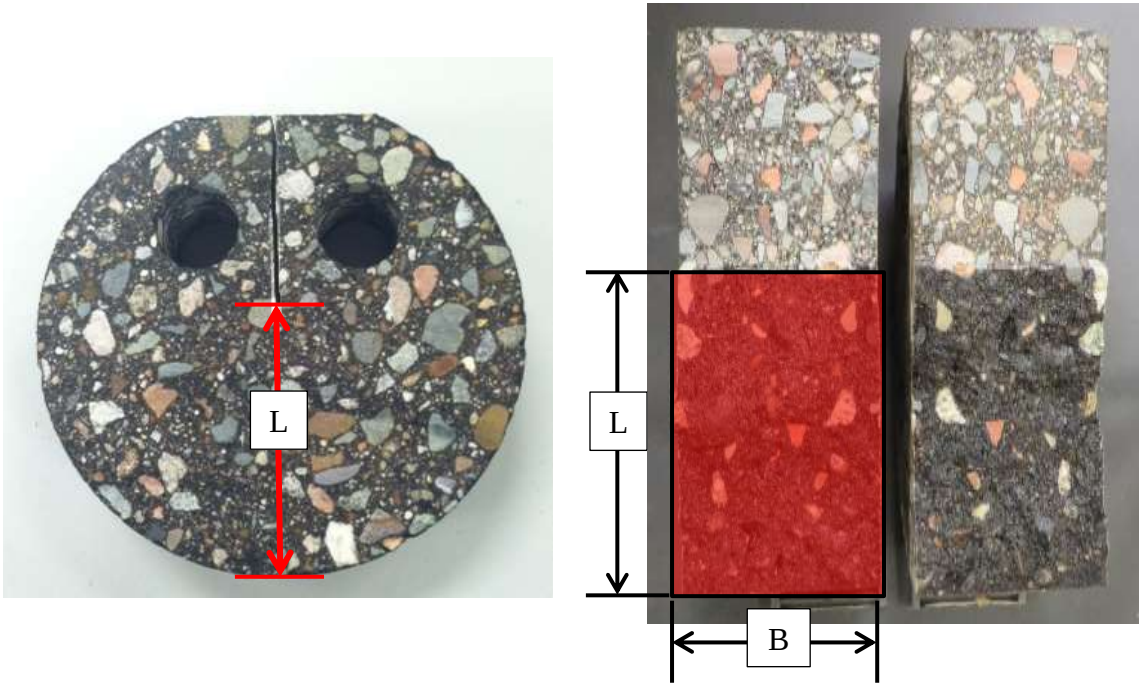
# Effects of Mix Composition on Fracture Energy






Fracture Area = Thickness * Length (initial ligament length)

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Marasteanu et al., 2012

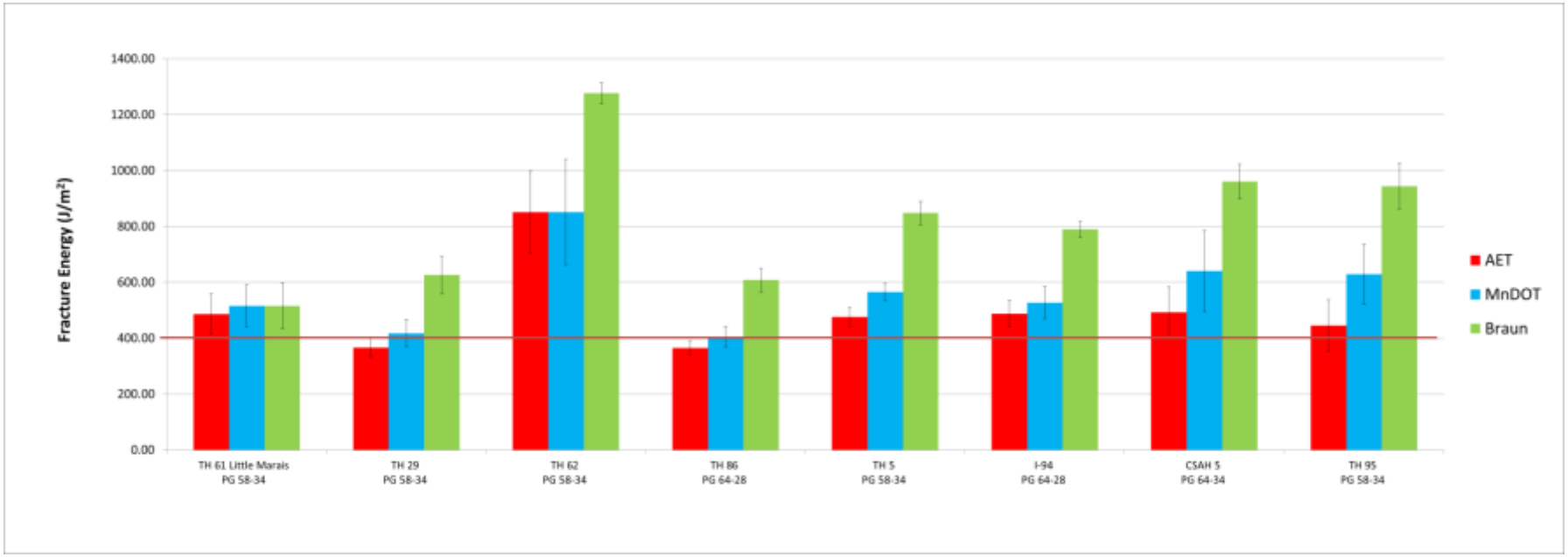
# *On-going Work*

- Use of validator to ensure test correctness
- Training of lab staff
- Round robin (inter-laboratory) repeatability study
  - *Samples collected this fall, with testing to start this spring*
- Participating labs include AET, Braun, MnDOT, and UMD

# *On-going Work*

- Study analyzing source of drop in fracture energy from mix design to production and placement
- Samples collected from 8 projects throughout the state


# *Average Fracture Energies:*
## *All Labs with all Four Specimens "Surviving" Test*



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