MECHANICAL PROPERTIES OF MIXTURES CONTAINING RAP

ISAP Working Group WG2:

Meeting on Cold Recycling of RAP

Elie Y. Hajj, Ph.D.
Assistant Professor
University of Nevada, Reno
United States

Fortaleza, Brazil
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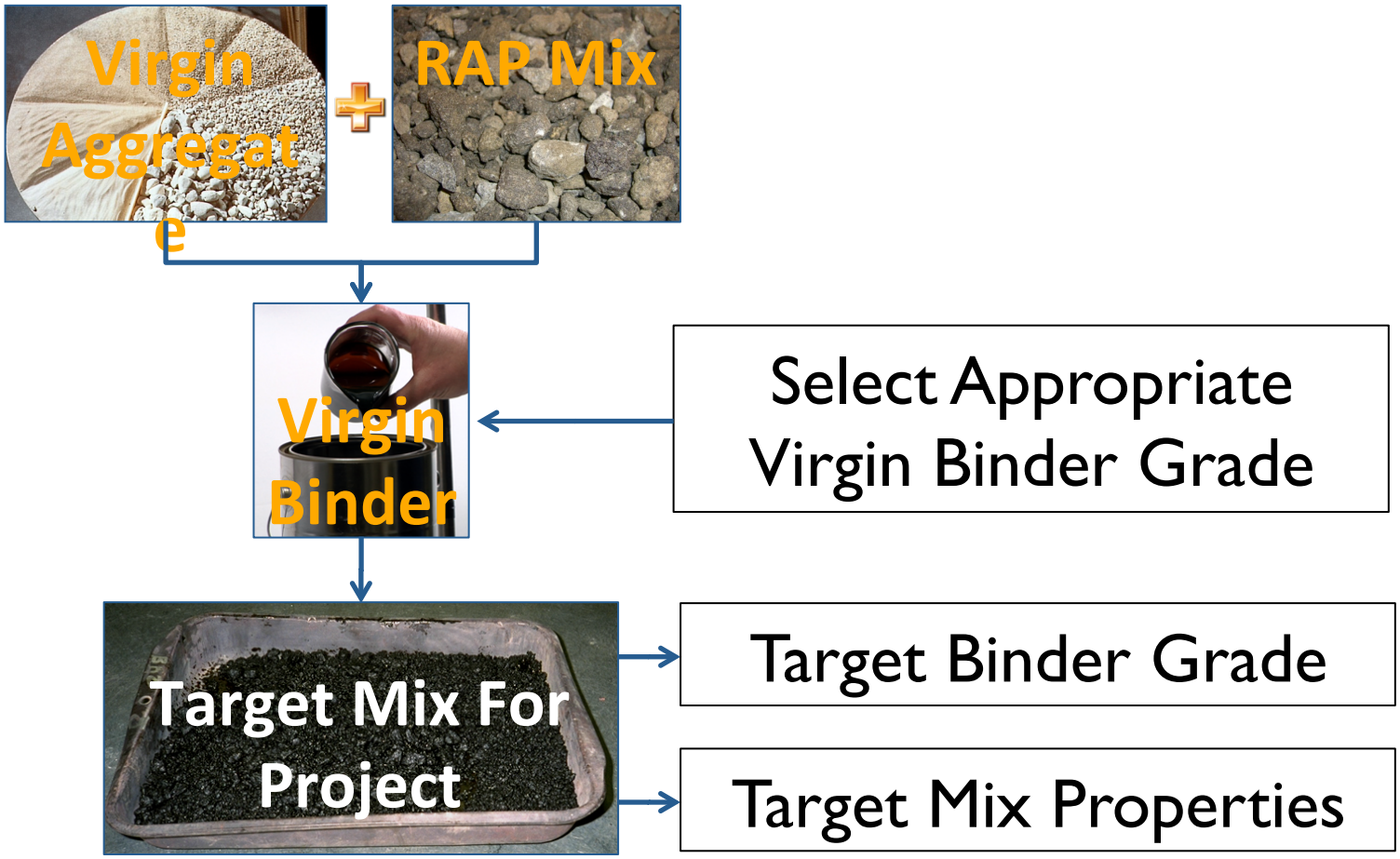
WESTERN REGIONAL SUPERPAVE CENTER

Introduction

Introduction



Impact of RAP on Mixtures' Properties
Review of Selected Literature


Stiffness


Rutting resistance


Fatigue resistance


Low temperature cracking


Moisture resistance

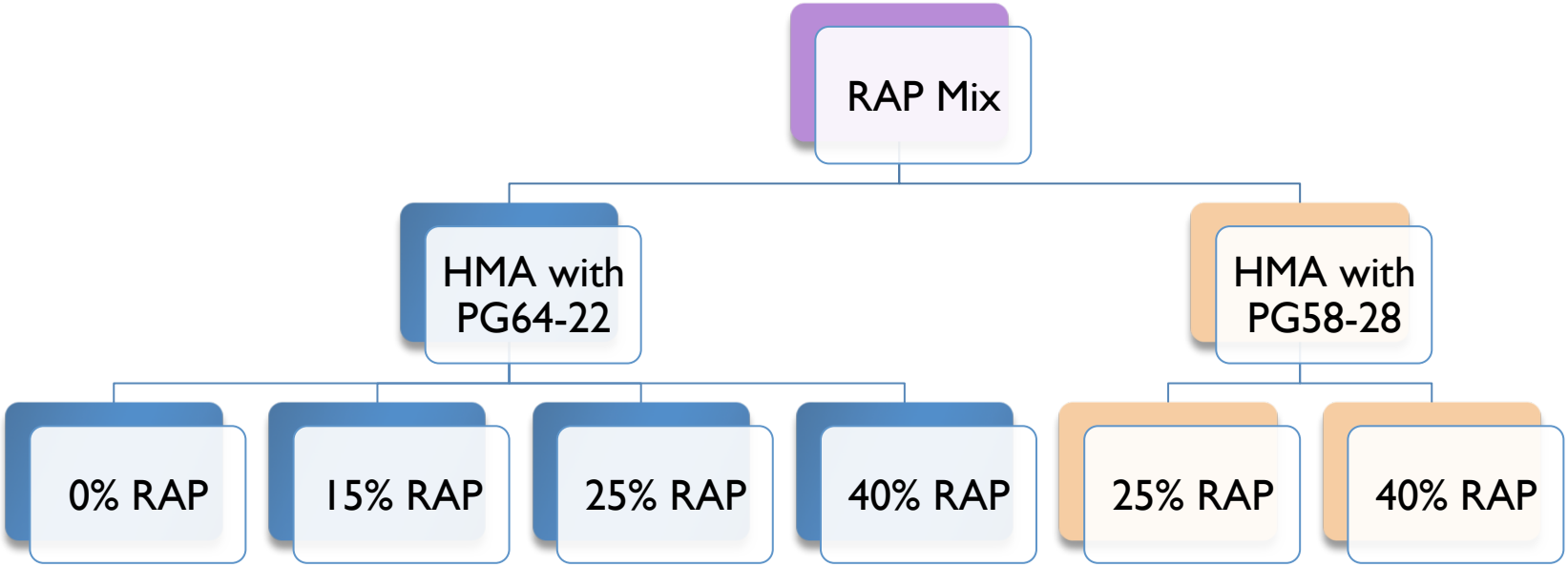
How Does RAP Affect Mixture Stiffness?

Impact of RAP on Mixtures' Properties
Stiffness

- *Li et al.(2004):* 10 mixes at 0, 20 and 40% RAP, two virgin asphalt binders (PG58-28 and PG58-34), and two RAP sources (RAP and millings).
  - 20-40% RAP →|E*|↑.
  - No significant impact for RAP on |E*| at low temperatures & high frequencies.

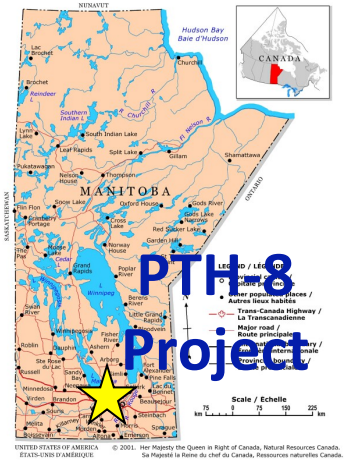
Impact of RAP on Mixtures' Properties
Stiffness

- *McDaniel et al. (2006):*
  - 15-25% RAP → No significant impact on |E*|.
  - 40% RAP → ↑|E*| at higher temperatures.



Impact of RAP on Mixtures' Properties
Stiffness

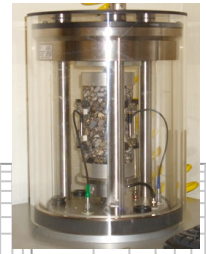
- *Loria et al. (2011):*
  - High RAP test sections in Manitoba, Canada
  - Constructed on 09/2009 (3rd & 4th lifts)

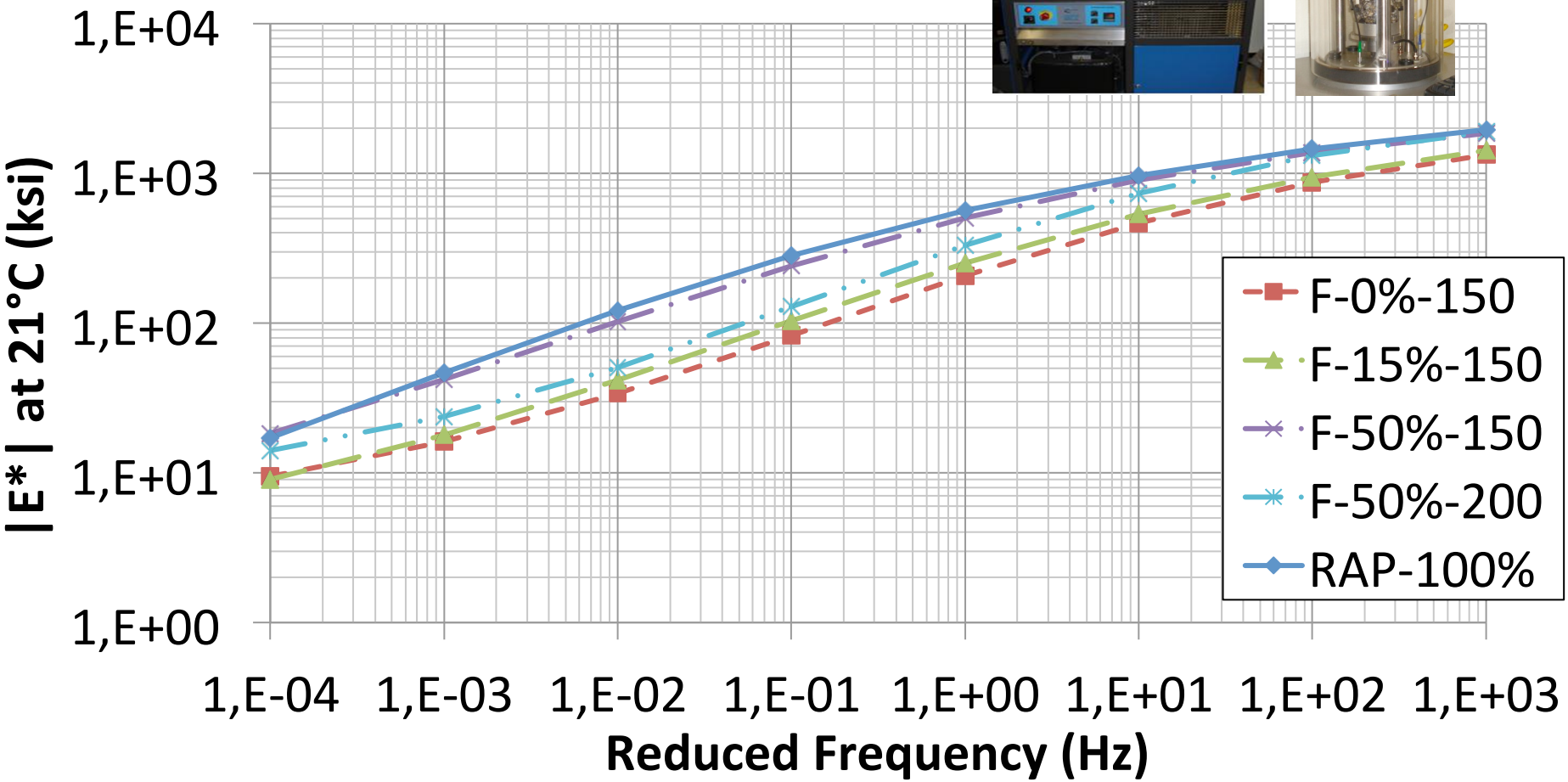


PG58-28	PG52-34	PG58-28	PG58-28
~1.5 miles	~1.5 miles	~1.5 miles	~1.5 miles
4th lift: HMA / 50% RAP	HMA / 50% RAP w/ grade change	HMA / 15% RAP	HMA / No RAP
3rd lift: HMA / 50% RAP	HMA / 50% RAP w/ grade change	HMA / 15% RAP	HMA / No RAP
2nd lift: HMA / 50% RAP			
1st lift: HMA / 50% RAP			

Impact of RAP on Mixtures' Properties
Stiffness

- *Loria et al. (2011): (Cont'd)*

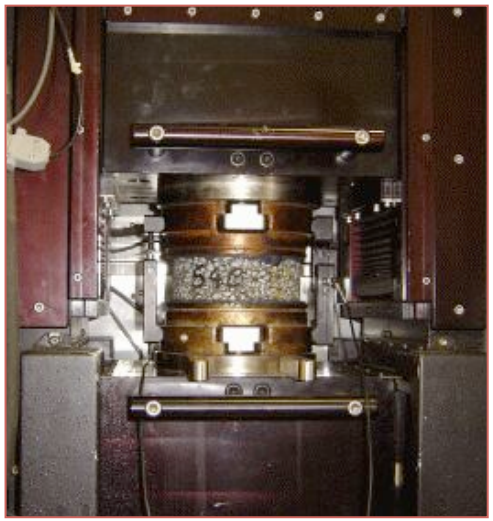


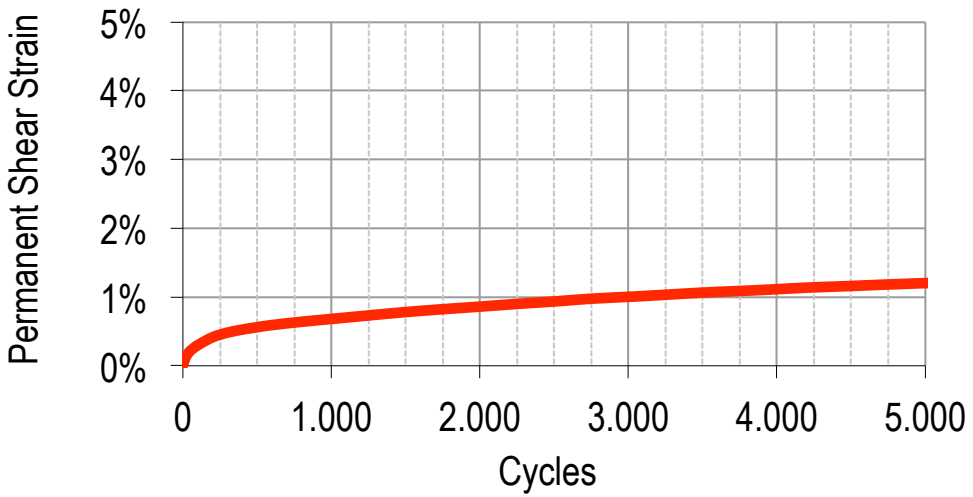


How Does RAP Affect Mixture Resistance to Rutting?

Impact of RAP on Mixtures' Properties
Rutting Resistance

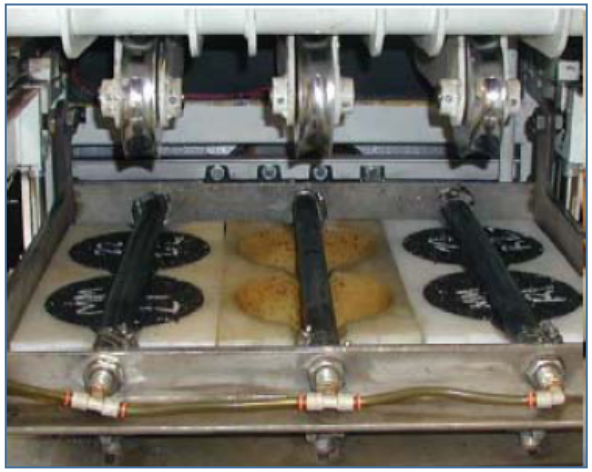
- *NCHRP 9-12 (2000):*
  - Impact of 0,10, 20, and 40% RAP content on mixtures' resistance to rutting.
  - Generally, ↑ RAP content → ↓Shear deformation → ↑ rutting resistance

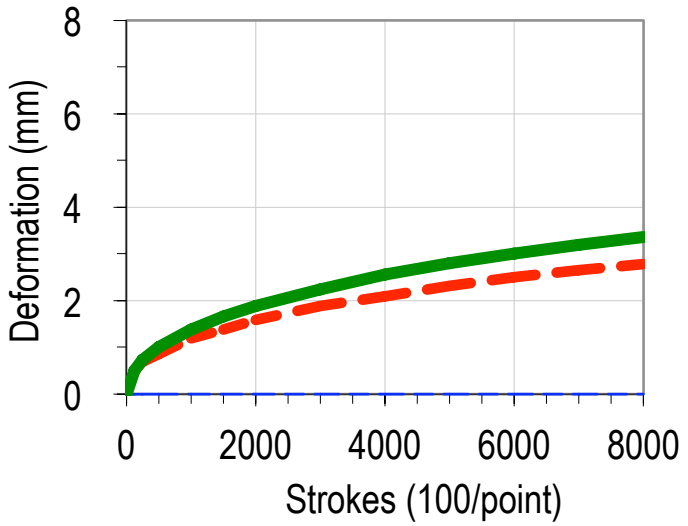




Impact of RAP on Mixtures' Properties
Rutting Resistance

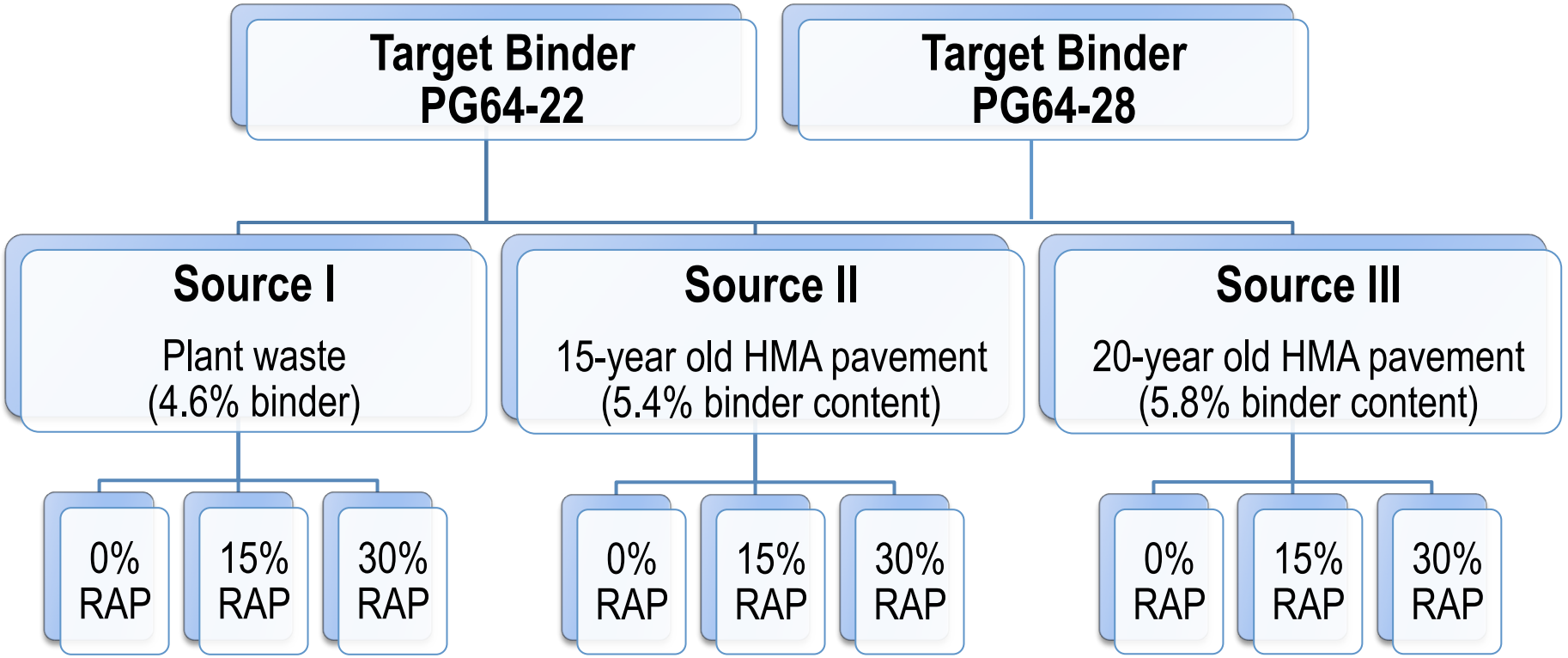
- *Xiao et al. (2007):* Effect of RAP (0 - 38%) and rubber on APA rutting resistance of HMA mixes.
  - ↑ RAP content → ↑rutting resistance
  - Rubberized binder increases the rutting resistance





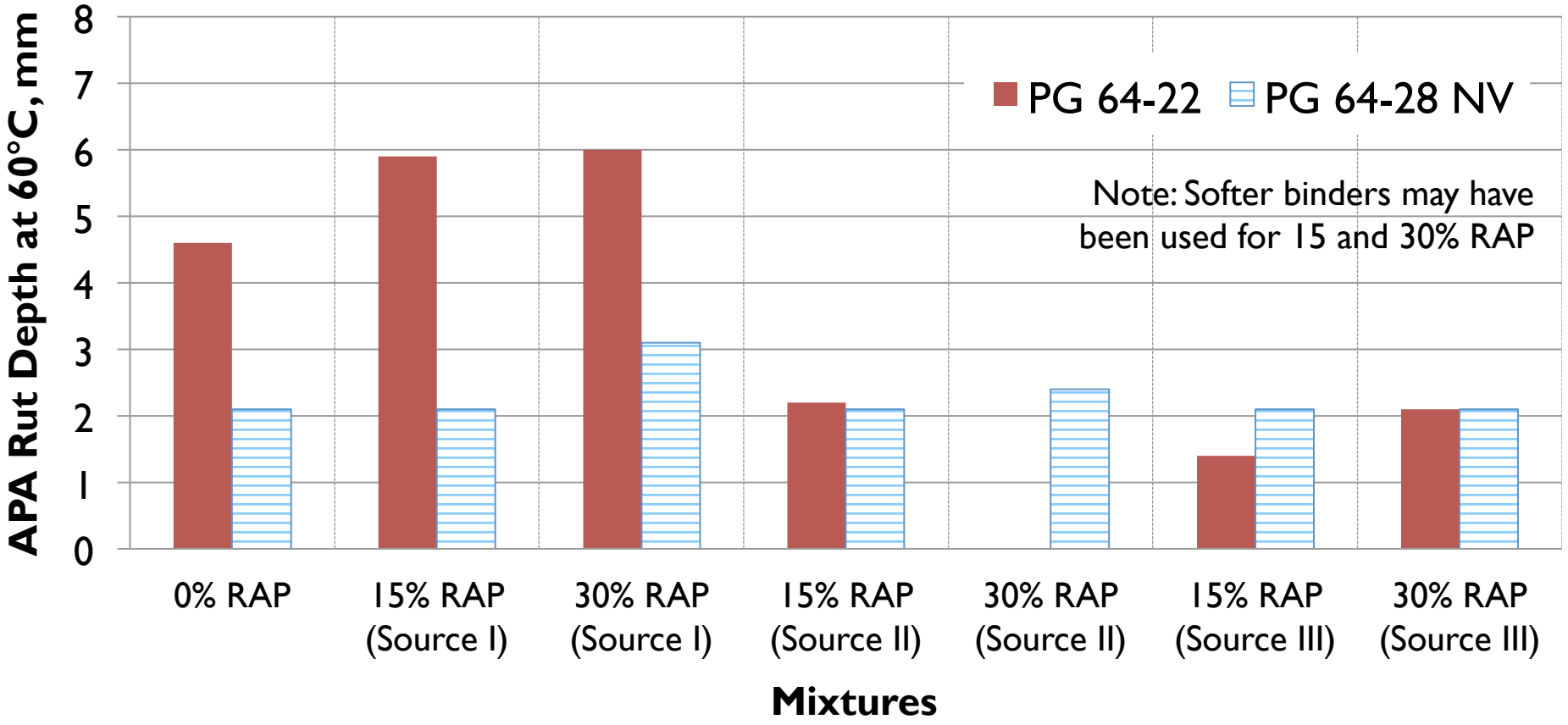
Impact of RAP on Mixtures' Properties
Rutting Resistance

- *Hajj et al. (2007):*



Impact of RAP on Mixtures' Properties
Rutting Resistance

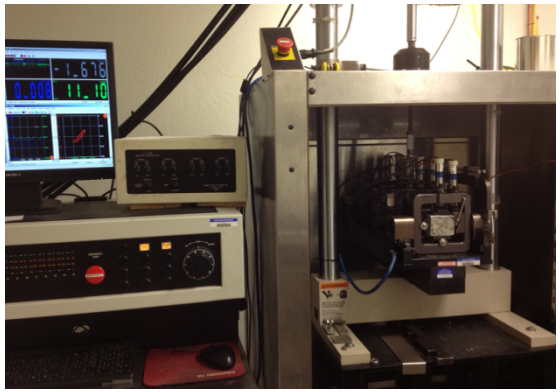
- *Hajj et al. (2007): (Cont'd)*
  - Criterion 8 mm at 60°C → good rutting resistance

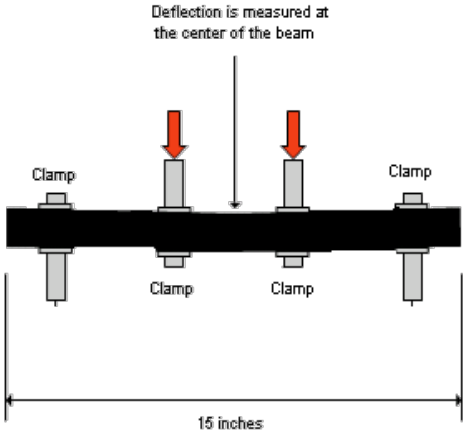


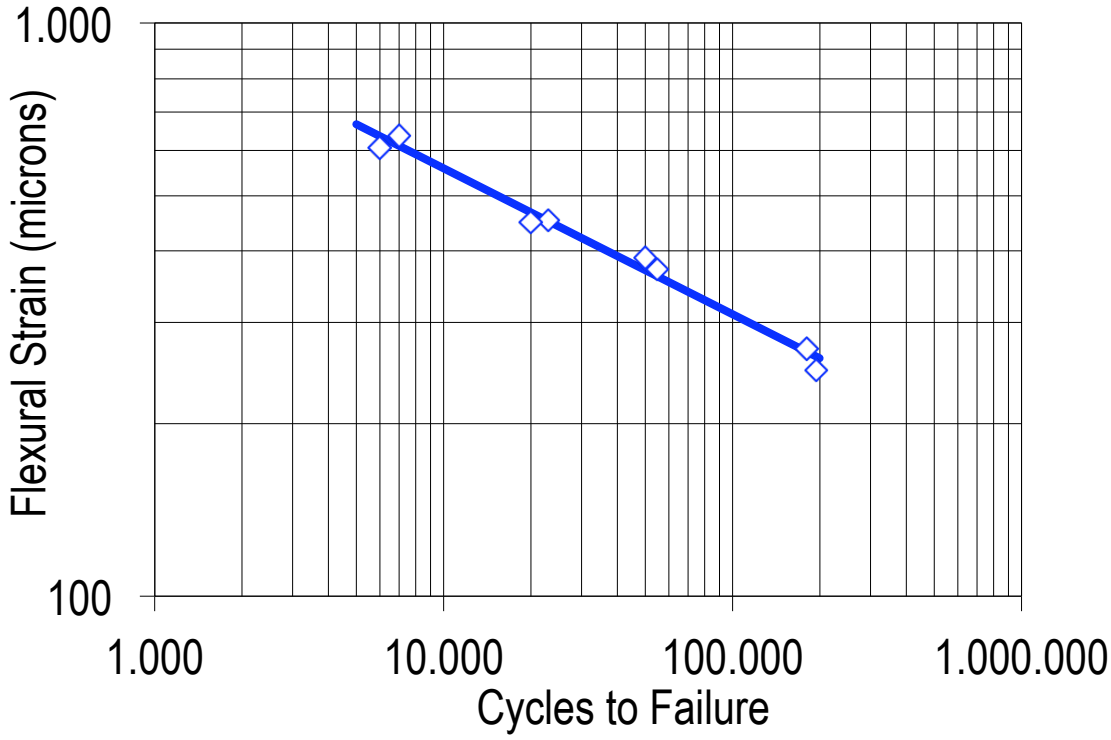
How Does RAP Affect Mixture Resistance to Fatigue?

Impact of RAP on Mixtures' Properties
Fatigue Resistance

- *Puttaguanta et al. (1997):* Estimated fatigue life of 0, 25 and 50% RAP mixes at 5, 22, and 40°C.







Impact of RAP on Mixtures' Properties
Fatigue Resistance

- *Puttaguanta et al. (1997):* Estimated fatigue life of 0, 25 and 50% RAP mixes at 5, 22, and 40°C.
  - At 5°C, 25 and 50% RAP mixes→ ↓ fatigue resistance.
  - At 22°C and 40°C all three mixes performed similarly.

Impact of RAP on Mixtures' Properties
Fatigue Resistance

- *NCHRP 9-12 (2000):* impact of 0,10, 20, and 40% RAP content on mixes' resistance to fatigue.
  - 10% RAP → no significant impact fatigue resistance.
  - 20 and 40% RAP → ↓ fatigue resistance.
  - 40% RAP mix resistance < 20% RAP mix resistance.

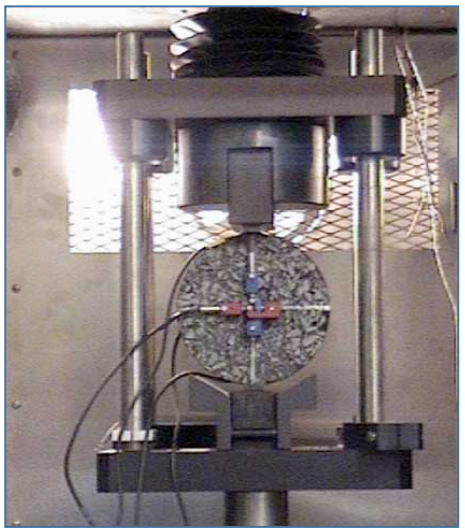
Impact of RAP on Mixtures' Properties
Fatigue Resistance

- *Hajj et al. (2007):* mixtures with 0, 15 and 30% RAP.
  - PG64-22 (unmodified):
    15% RAP → better or equivalent fatigue resistance.
  - PG64-28 (SBS polymer-modified):
    15-30% RAP → ↓in fatigue resistance but similar or better than unmodified asphalt binder.

How Does RAP Affect Mixture Resistance to Low Temperature Cracking?

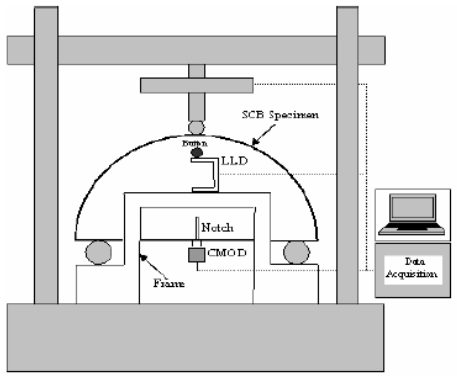
Impact of RAP on Mixtures' Properties
Low Temperature Cracking Resistance

- *NCHRP 9-12 (2000):* Resistance to low temperature cracking using IDT.
  - 10% RAP → no impact on low temperature cracking resistance.
  - >10% RAP → ↓ low temperature cracking resistance.



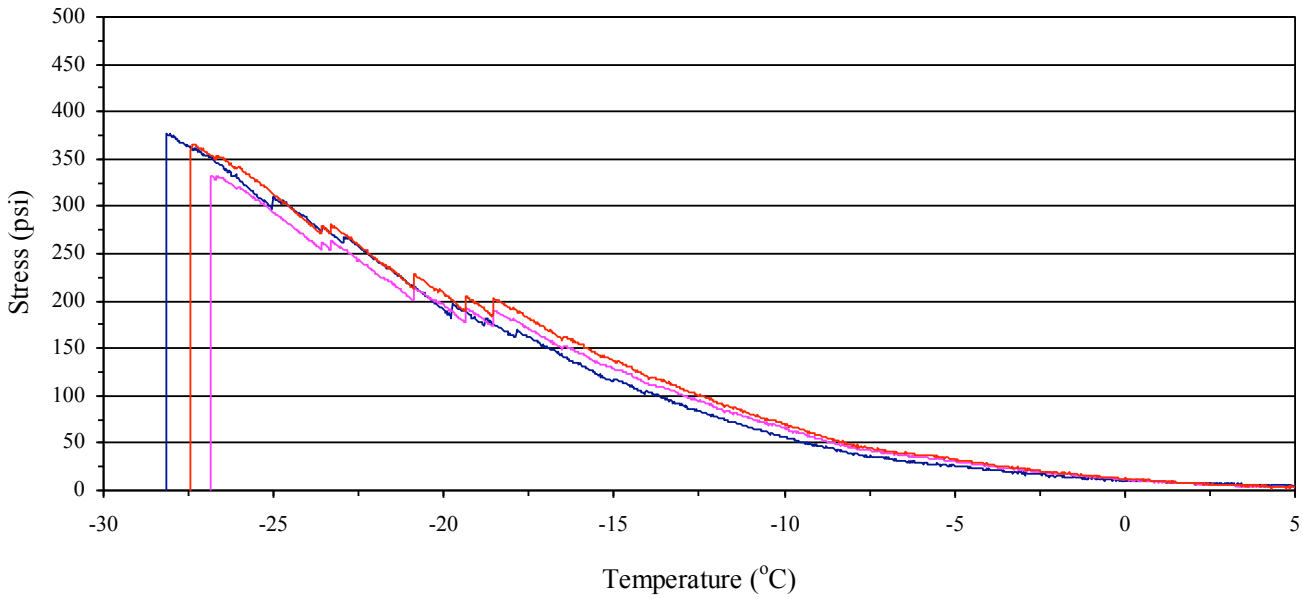
Impact of RAP on Mixtures' Properties
Low Temperature Cracking Resistance

- *Li et al.(2004 & 2008):* 10 RAP mixes with 0-40% RAP using IDT test and SCB fracture test.
  - IDT: ↑RAP → ↓ low temperature cracking resistance.
  - SCB fracture test: significant effect for RAP content.
    - 20% RAP → no impact on low temperature cracking resistance.
    - >20% RAP → significant ↓ in resistance to low temperature cracking.



Impact of RAP on Mixtures' Properties
Low Temperature Cracking Resistance

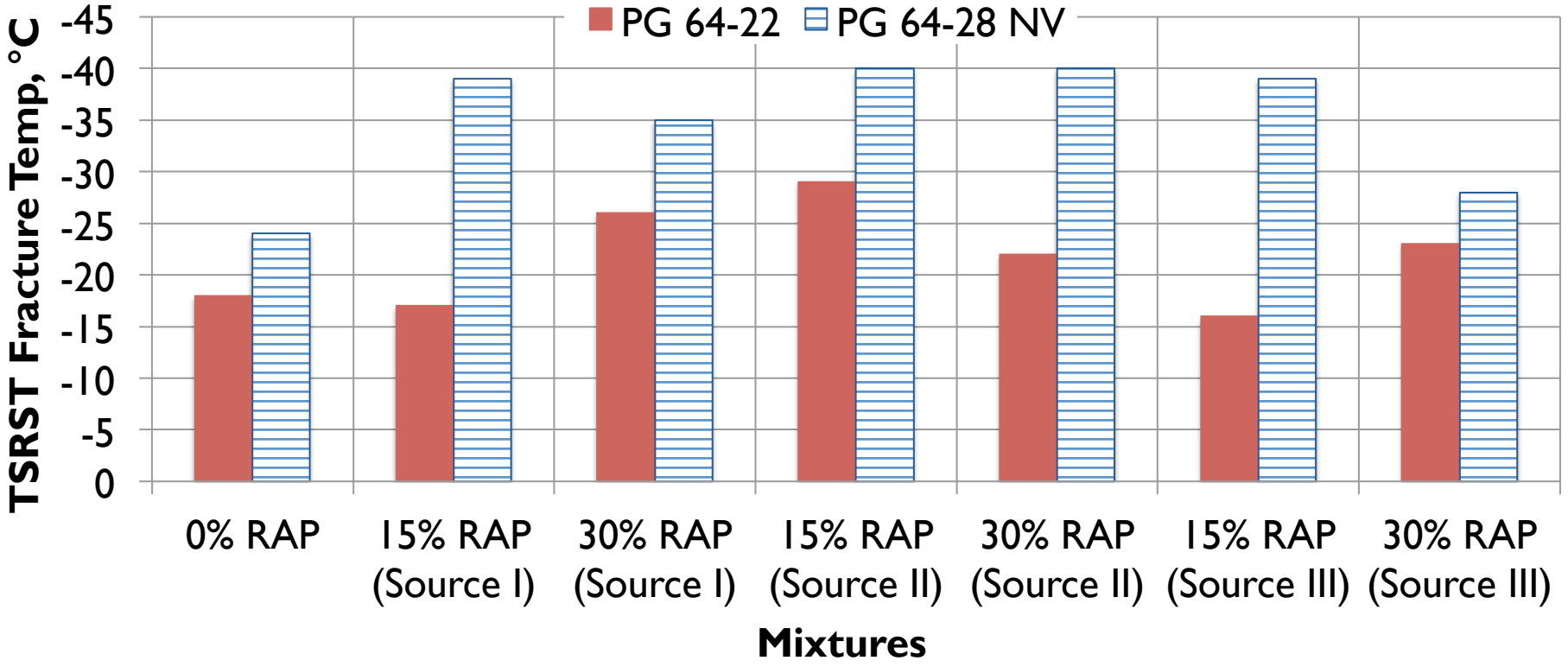
- *Hajj et al. (2007):* RAP mixes with 0,15 and 30% RAP using TSRST



Impact of RAP on Mixtures' Properties
Low Temperature Cracking Resistance

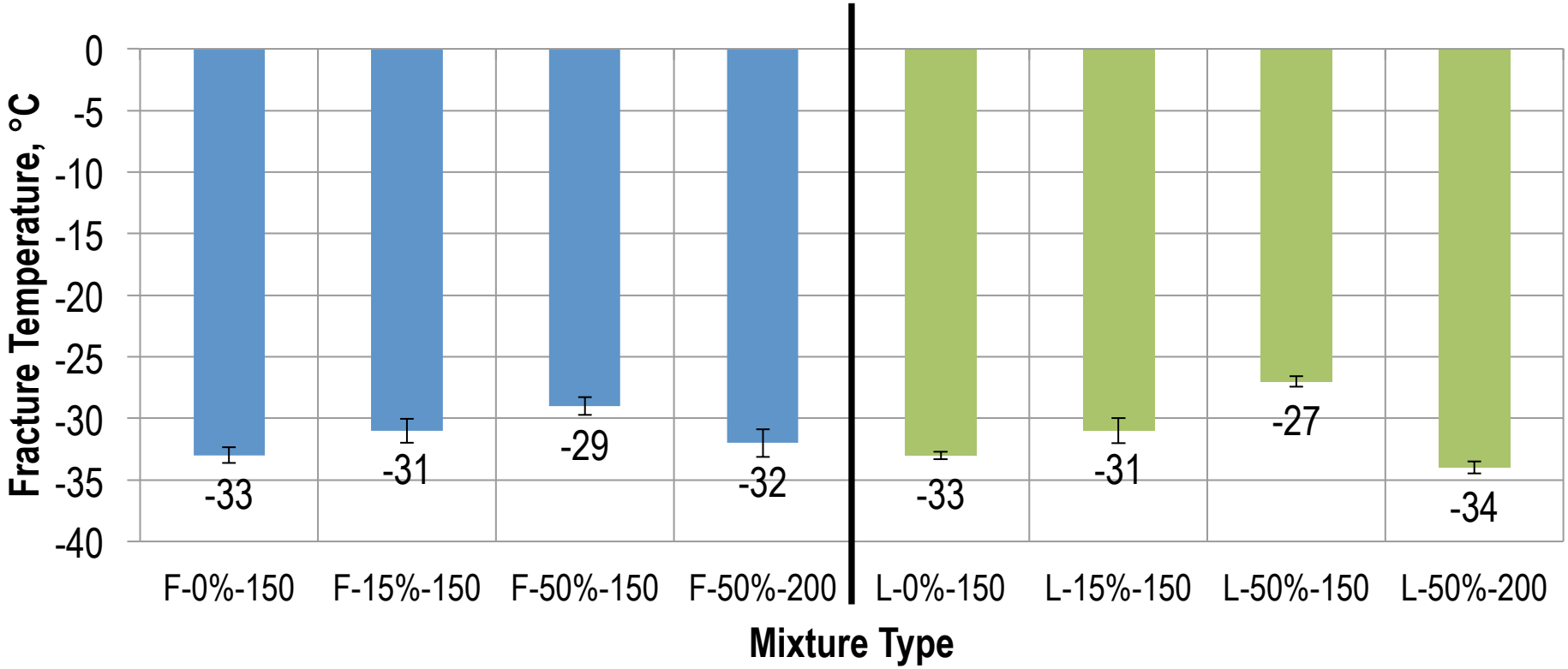
- *Hajj et al. (2007):* RAP mixes with 0,15 and 30% RAP using TSRST

Note: Softer binders may have been used for 15 and 30% RAP



Impact of RAP on Mixtures' Properties
Low Temperature Cracking Resistance

- *Loria et al. (2011):*
  - High RAP test sections in Manitoba, Canada



How Does RAP Affect Mixture Resistance to Moisture Damage?

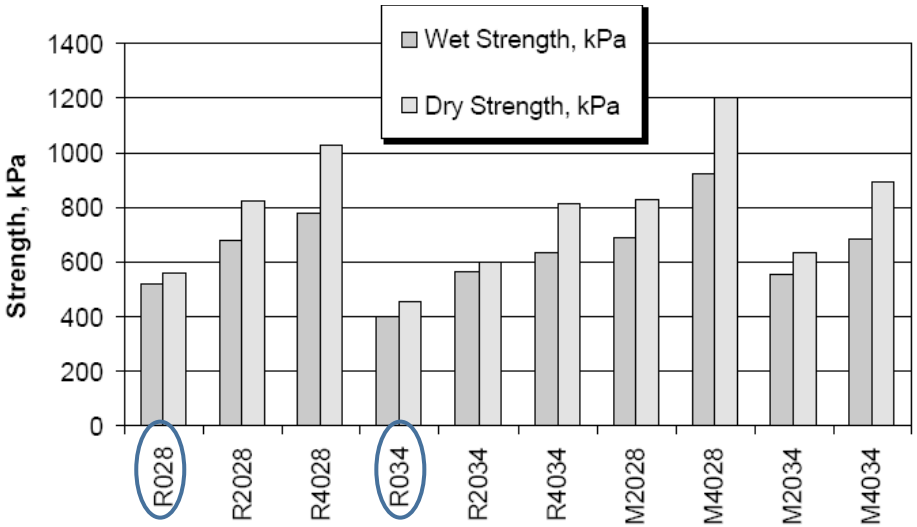
Impact of RAP on Mixtures' Properties
Resistance to Moisture Damage

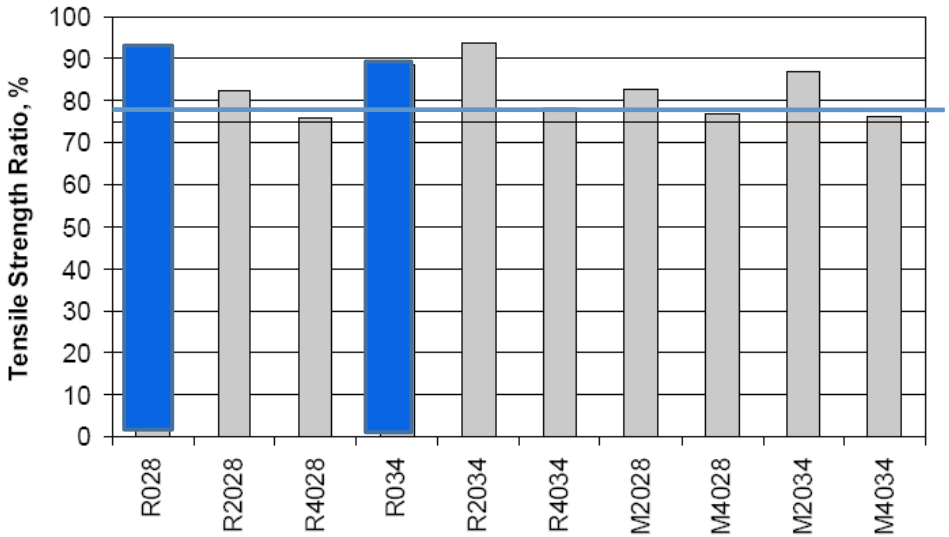
- *Puttaguanta et al. (1997)*: mixes with 0, 25 and 50% RAP using AASHTO T283 test
  - 25 and 50% RAP → significant ↑ in moisture resistance.

Property	Virgin mix	RAP mix		Allowable limit
		25%	50%	
Tensile strength ratio, %	59	81	91	> 80
Resilient modulus ratio, %	68	85	90	> 80

Impact of RAP on mixtures' properties
Resistance to Moisture Damage

- *Li et al.(2004):* 10 RAP mixtures with 0-40% RAP using AASHTO T283 test.
  - TSR of 20 and 40% RAP mixes > 75% (criterion)
  - ↑RAP→ ↑TS (both wet and dry) but ↓TSR





Impact of RAP on mixtures' properties

Resistance to Moisture Damage

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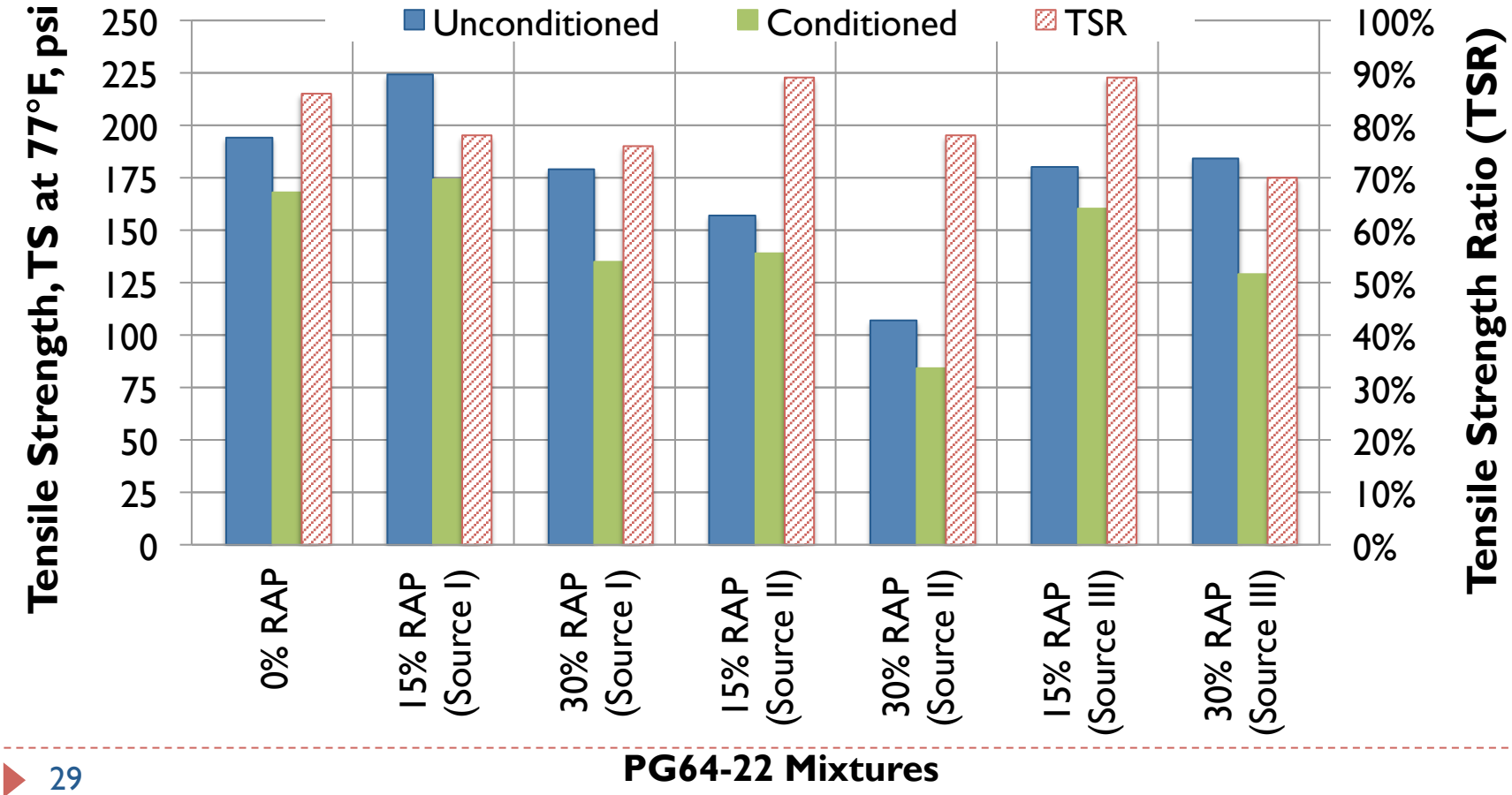
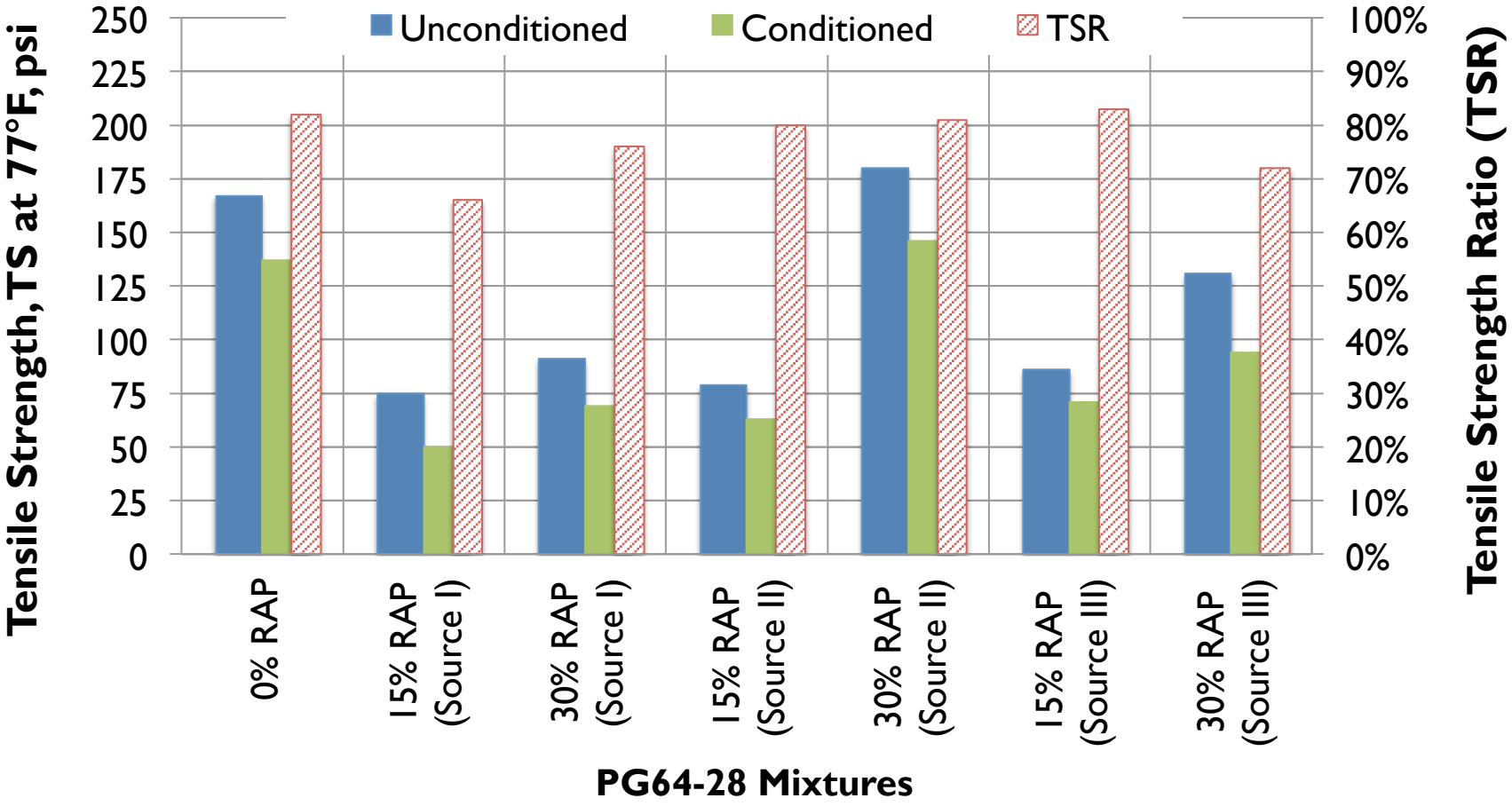


Impact of RAP on mixtures' properties

Resistance to Moisture Damage

- *Hajj et al. (2007):* (cont'd)



Impact of RAP on mixtures' properties
Resistance to Moisture Damage

- *Hajj et al. (2007): (cont'd)*
  - 15 and 30% RAP → acceptable moisture resistance (TSR>70).
  - 15 and 30% RAP → ↓ TS conditioned and unconditioned.

Impact of RAP on mixtures' properties

Resistance to Moisture Damage

- *Loria et al. (2011):*
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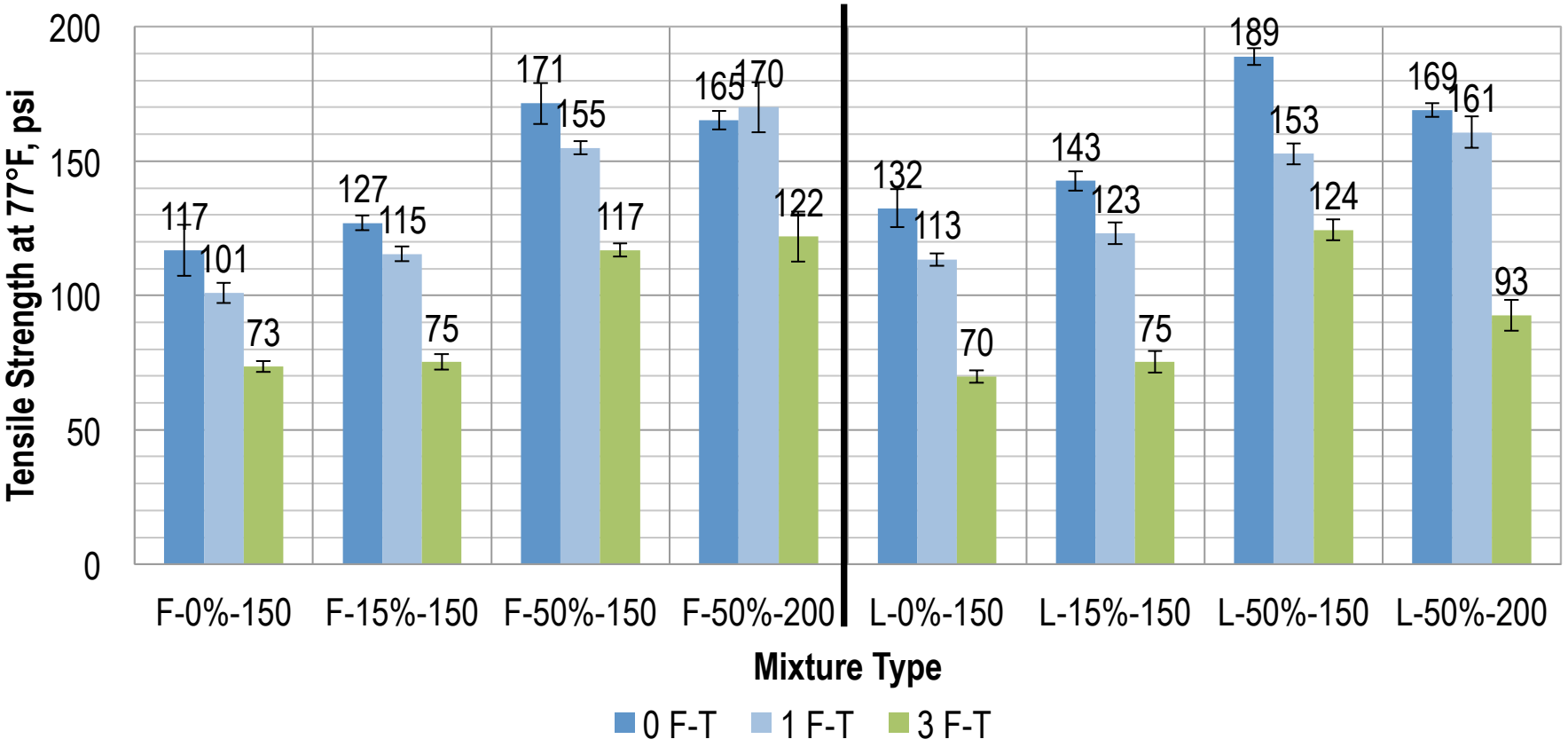

Impact of RAP on mixtures' properties

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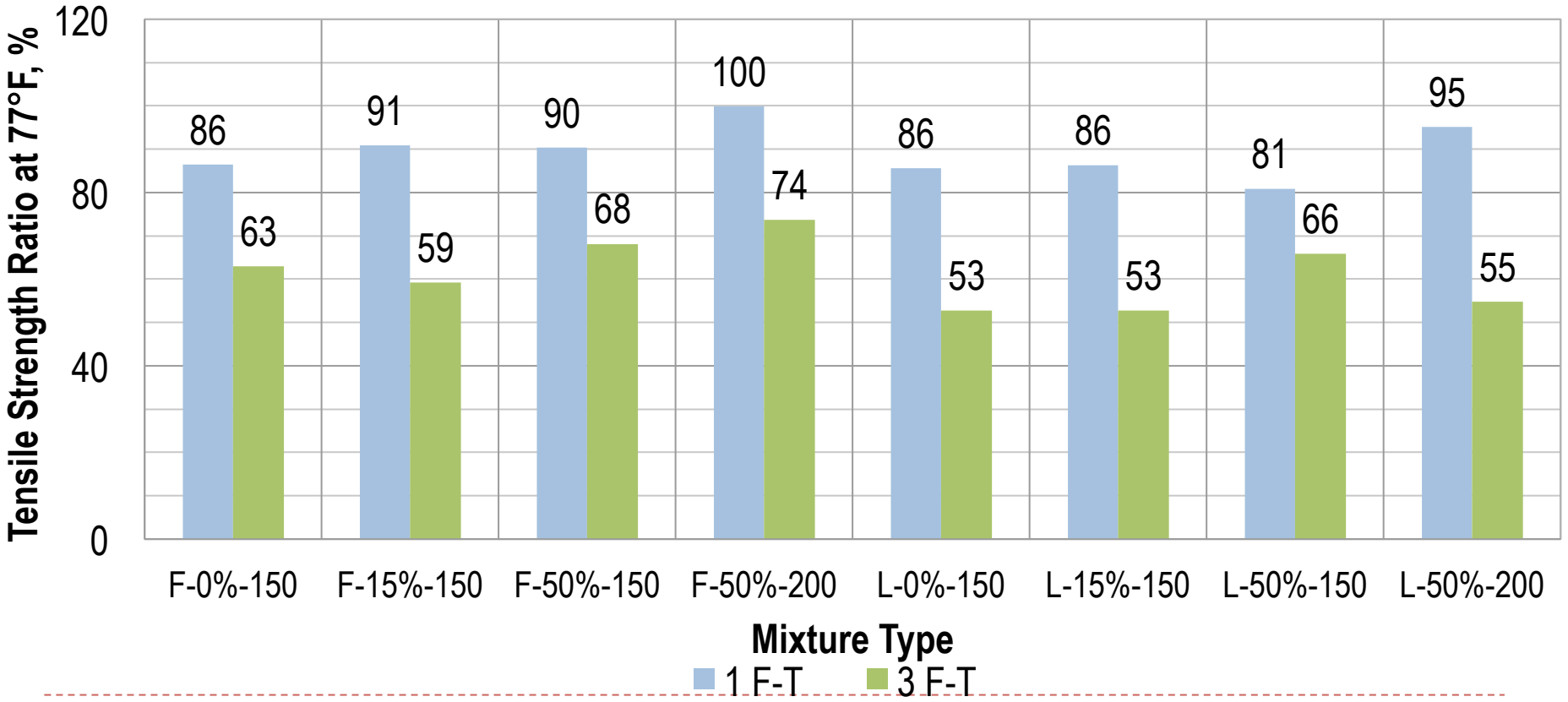

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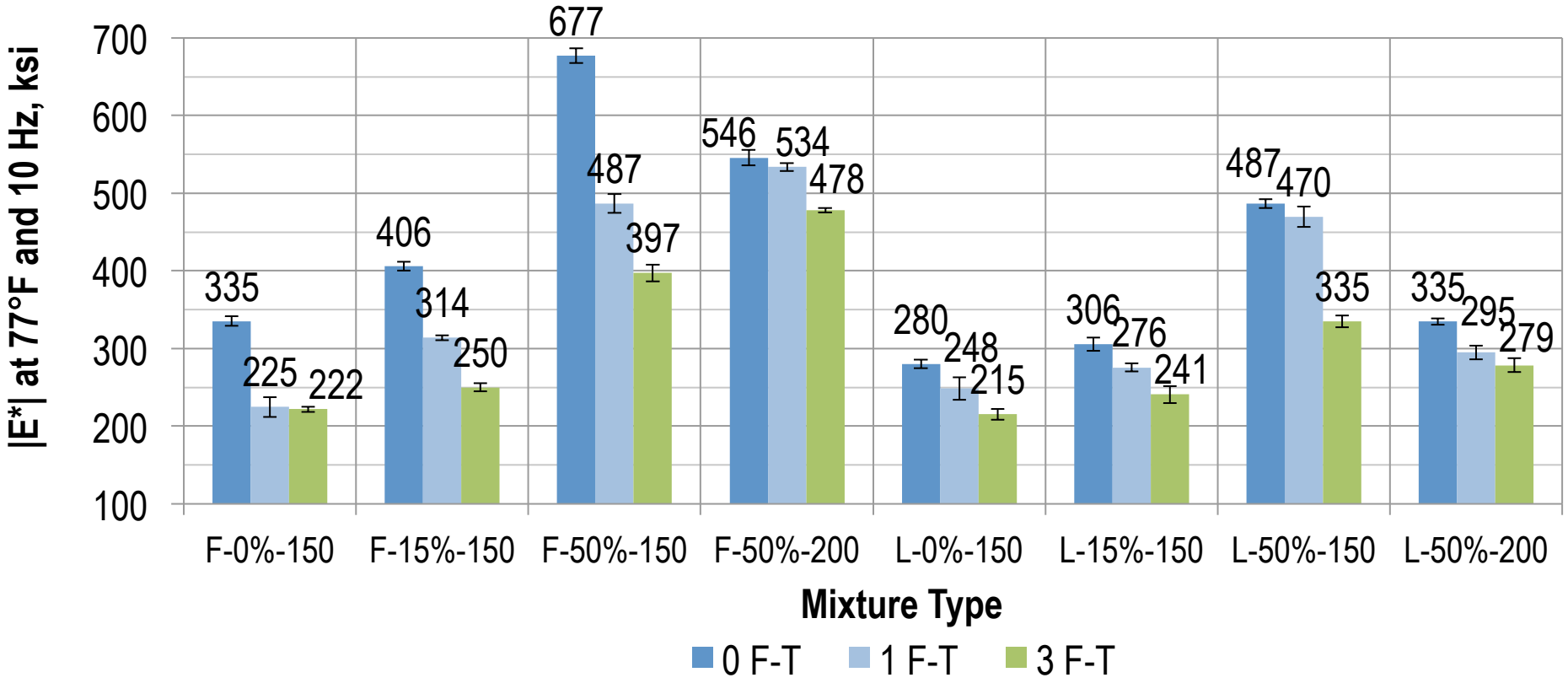

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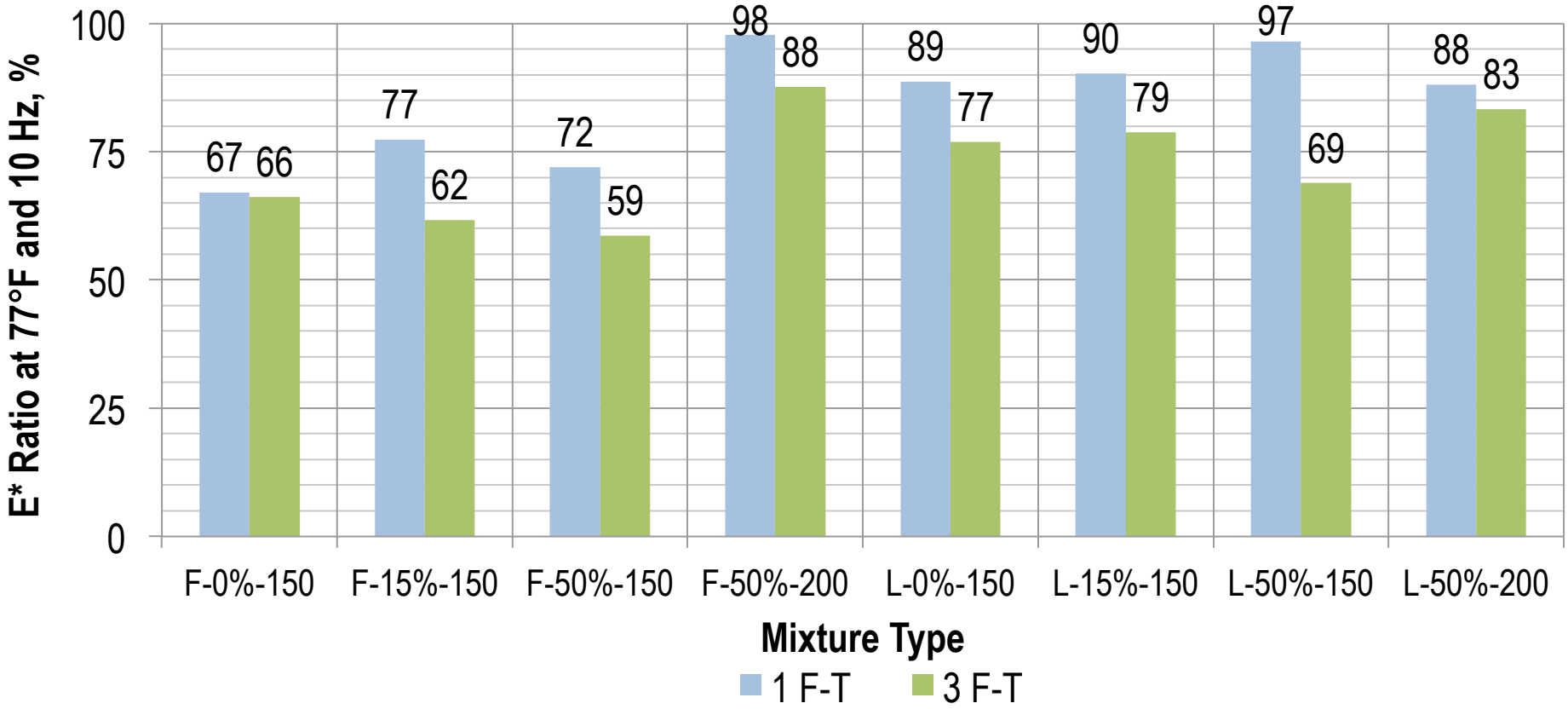


How About Field Performance?

Field performance (After West R.)

Washington State

(Source: www.morerap.us)

- WA-RD-98.1, 1986
- Title: *Hot Mix Recycling Evaluation in Washington*
- Authors: Peters, et al.
- Scope: 16 projects, RAP contents from 8 to 79% (half ≥ 70%), projects ranged from 1.5 to 10 years old

Field performance (After West R.)

Washington State

(Source: www.morerap.us)

- Findings:
  - WSDOT's initial two projects…are still performing very well.
  - The early data indicates equally promising results for the 14 other projects.

Field performance (After West R.)

Louisiana

(Source: www.morerap.us)

- LTRC Report No. 216, April 1995
- Title: *Evaluation of Recycled Projects for Performance*
- Scope: 10 projects, RAP content: 20 to 50%, data covered a six to nine years, evaluated pavement condition ratings, serviceability, structural analysis, and mix and binder properties

Field performance (After West R.)

Louisiana

(Source: www.morerap.us)

- Findings:
  - Pavements containing RAP performed similarly to conventional mixtures for a period of six to nine years of service life
  - Pavements with RAP exhibited slightly more distress with respect to longitudinal cracking
  - The substitution of up to 15 % [RAP in wearing courses] can provide acceptable performing pavements as long as the 12,000 poise viscosity limitation is maintained.

Field performance (After West R.)

Connecticut

(Source: www.morerap.us)

- Report No.: FHWA-CTRD-647-4-87-1
- Title: Performance Evaluation of Hot Mixed Recycled Pavement –Route 4, Burlington
- Authors: Ganung and Larsen
- Scope: conventional and 30% RAP, performance compared at 6 years of service

Field performance (After West R.)

Connecticut

(Source: www.morerap.us)

- Findings:
  - No rutting was detected
  - Roughness was low
  - Extracted asphalt viscosities were higher for recycled versus control, possibly explaining for the greater cracking on the recycled
  - This condition was reversed on the overlaid sections

Field performance (After West R.)

Georgia

(Source: www.morerap.us)

- TRR 1507, 1995
- Title: *Performance of Recycled Hot-Mix Asphalt Mixtures in Georgia*
- Authors: Kandhal, et al.
- Scope: Detailed comparison of 5 pairs of recycled versus control projects, followed by comparison of a larger set of control and recycled HMA projects. RAP contents range from 10 to 25%

Field performance (After West R.)

Georgia

(Source: www.morerap.us)

- Findings:
  - For the 5 paired comparisons, there was no rutting, raveling, or fatigue cracking in either the recycled or conventional sections.
  - Comparison of recycled vs. conventional mixes on 15 projects indicated the RAP mixes performed equal to or better than the virgin mixes.

Field performance (After West R.)

California

(Source: www.morerap.us)

- Title: *Comparative Analysis of Long-Term Field Performance of Recycled Asphalt in California Environmental Zones*, TRB 2008

- Authors: Zaghloul and Holland

- Scope: 60 RAP sections (up to 15% RAP) in 3 climatic zones in CA, evaluations at 5 to 9 years of service, rated by Structural Service Life, Distress Service Life, and Roughness Service Life

Field performance (After West R.)

California

(Source: www.morerap.us)

- Findings:
  - Performance of RAP pavements differs for the three climatic zones
    - North Coast climatic zone –Excellent to good performance of pavements with RAP
    - Mountain climatic zone –structural performance was marginal, but distress performance was poor
    - Desert climatic zone –Structural performance was good but distress performance was poor

Field performance

LTPP – Specific Pavement Study 5

- West et al. (2011) compared statistically the performance of virgin to 30% RAP mixes using 18 test projects build as part of SPS-5 .
- Seven different type of distresses were examined.
  - Overlay mixes with 30% RAP perform as well as virgin mixes in terms of IRI, rutting, block cracking and raveling.
  - About a third of the projects had more longitudinal cracking or transverse cracking in the overlays containing RAP.

Field performance

- More data available in literature documenting field performance of RAP mixes…

Keys to Managing RAP Variability

West R. (2009), Better Roads

1. Avoid Contamination:
   - Contamination can occur from dumping general road debris with dirt and vegetation on the pile, including milled-up paving fabrics in the pile, …
2. Mix as You Feed:
   - Randomly dig into different areas of the pile so that the material going into the crusher at any time gets mixed up and is not just from one place in the pile.
3. Don't Over-Crush:
   - The majority of contractors crush all RAP to a single maximum size, such as minus 1/2-inch, or minus 5/8-inch, so that the crushed RAP can be used in a wide range of mixes from black base to surface mixes. The price paid for this convenience is that as larger aggregate particles in the RAP get crushed, more dust is generated. The excess dust will often limit how much of the RAP can be used in a new mix design.

Keys to Managing RAP Variability

West R. (2009), Better Roads

4. Fractionating:
   - Screening of RAP into two or more sizes.
   - Couple of benefits to fractionating RAP and also additional costs with the practice.
   - Primary benefit is that it provides much greater flexibility in designing mixes. In general, it is easier to use more total RAP in a mix when it is fractionated compared to a crusher-run RAP
5. Stop Processing RAP When it Rains:
   - RAP stockpiles produced during a heavy rains may change in gradation affecting mix properties. It makes sense that RAP will not screen as efficiently when it is wet because the material sticks together more and the screens tend to clog up or blind.

Keys to Managing RAP Variability

West R. (2009), Better Roads

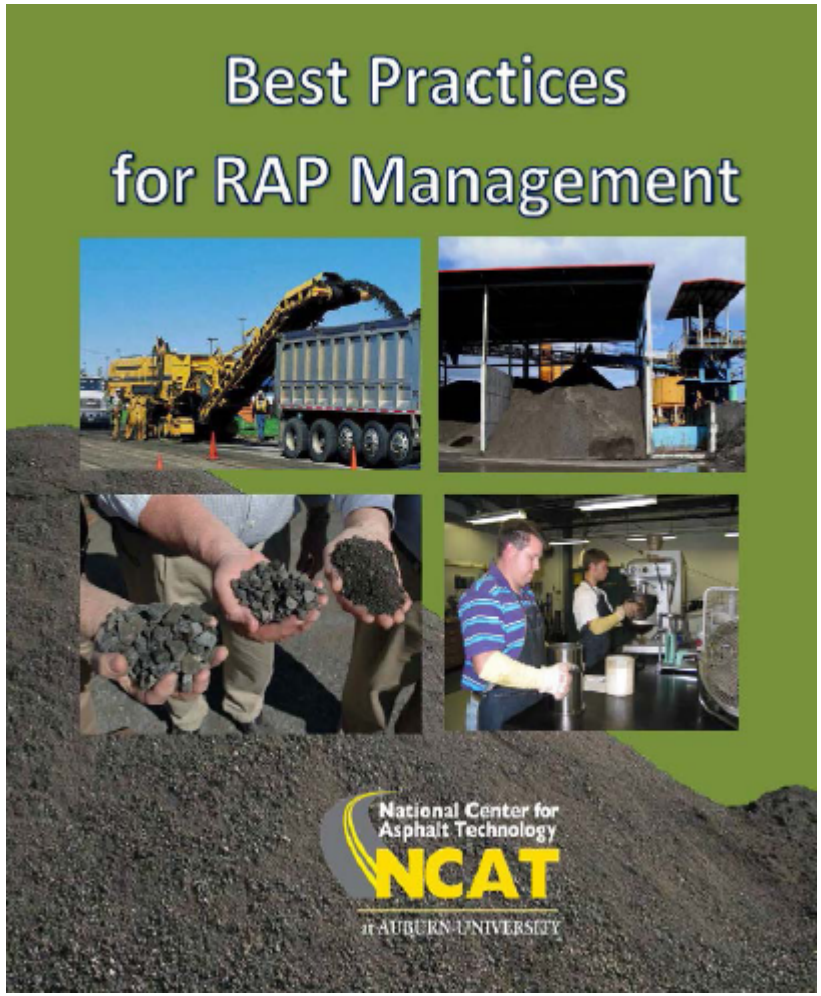
6. Blend Again When Moving:
   - Usually, after processing RAP through a crushing system and/or fractionation unit, the new stockpile(s) will have to be moved from the processing location to another location closer to the asphalt plant's cold feed bins.
   - Contractors want to avoid moving materials any more than needed because it adds cost to the materials, but moving the processed RAP materials is an opportunity to further improve consistency.
   - Moving processed RAP should be done so as to further mix and blend the material as it is being loaded and unloaded.
   - However, sloppy moving practices can also lead to segregation, which will have the opposite effect on consistency.

Keys to Managing RAP Variability

West R. (2009), Better Roads

6. Cover, Slope, and Pave:
   - RAP stockpiles tend to retain a lot of moisture and that will increase the drying and heating cost for superheating the virgin aggregate and limit the mix production rate.
   - As with virgin aggregates, paving under stockpiles provides an even foundation to minimize yard loss and contamination underlying materials.
   - Sloping the surface under the stockpile away from the side where the front-end loader picks up will allow rainwater to drain away, so that drier materials go into the plant.

BEST PRACTICES FOR RAP MANAGEMENT



Best Practices for RAP Management NCHRP 9-46 (NCAT)

- Keep large milling stockpiles separate, no additional processing to minimize P0.075
- Multi-source stockpiles can be made into a consistent RAP through processing. Avoid over-crushing by screening material prior to crusher.
- Variability guidelines should be used rather than method specifications for processing
- Fractionation is helpful for mix designs with high RAP contents
- Sampling & testing frequency should be consistent with aggregate QC (typically 1 per 1000 tons of RAP)
- Use a loader to build mini-stockpiles for sampling
- RAP aggregate can be recovered for testing using solvent extraction or ignition method.

References

- Puttagunta, R., Oloo, S.Y., and Bergan, A.T. (1997). "A Comparison of the Predicted Performance of Virgin and Recycled," *In Candian Journal of Civil Engineering*, Vol. 24, pp. 115-121. *Puttaguanta*
- McDaniel, R. S., Soleymani, H., Anderson, R. M., Turner, P., and Peterson, R. (2000). "Incorporation of Reclaimed Asphalt Pavement in the Superpave System," NCHRP 9-12, National Cooperative Highway Research Program, Transportation Research Board, National Research Council.
- Li, X., Clyne, T. R., and Marasteanu, M. O. (2004). "Recycled Asphalt Pavement (RAP) Effects on Binder and Mixture Quality," Report No. MN/RC – 2005-02, Minnesota DOT, Research Services Section.
- McDaniel, R. S. (2006). *Summary of State Specifications on RAP*, North Central Superpave Center, November.
- Hajj, E.Y., Sebaaly, P. E., Shrestha, R. (2007). "A Laboratory Evaluation on the Use of Recycled Asphalt Pavements in HMA Mixtures," Final Report, Regional Transportation Commission.
- Xiao, F., Amirkhanian, S., and Juang, C. H. M. (2007). "Rutting Resistance of Rubberized Asphalt Concrete Pavements Containing Reclaimed Asphalt Pavement Mixtures," *In Journal of Materials in Civil Engineering*, Vol. 19, No. 6, June 1, pp.475-483.
- Loria, L., **Hajj, E.Y.**, Sebaaly, P. E., Barton, M., Kass, S., and T. Liske. "Performance Evaluation of Asphalt Mixtures with High Recycled Asphalt Pavement Content," Transportation Research Record: Journal of the Transportation Research Board, No. 2208, Vol. 2, , Washington, D.C., 2011, pp. 72–81.
- Li, X., Marasteanu, M. O., Christopher W., and Clyne, T. R. (2008). "Effect of RAP (Proportion and Type) and Binder Grade on the Properties of Asphalt Mixtures," In Transportation Research Board 86th Annual Meeting Compendium of Papers CD-ROM, TRB, National Research Council.
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