Geological Engineering | Transportation Geotechnics | Civil & Environmental Engineering

Behavior of Recycled Concrete Aggregate as Unbound Road Base

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RMRC

THE UNIVERSITY of WISCONSIN MADISON

Objective of Pool Fund Project

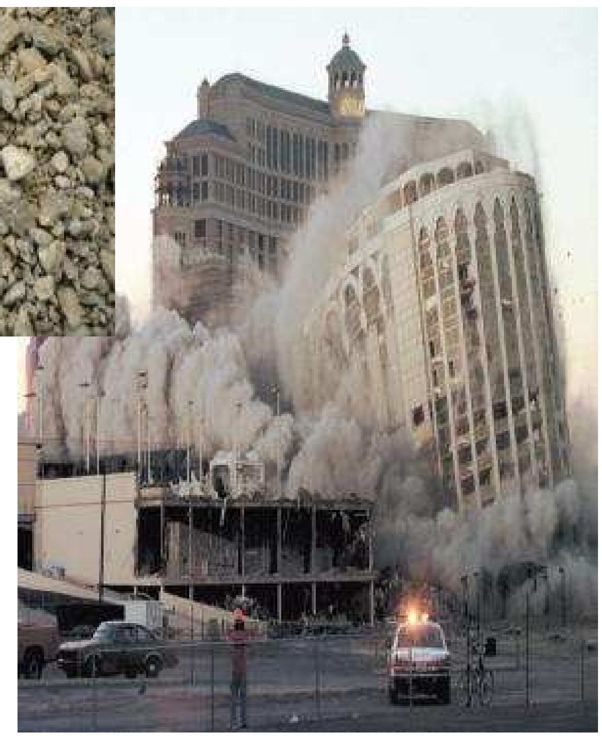
- Characterize properties of recycled concrete aggregate (and also recycled asphalt pavement) as unbound base
- Determine how RCA behaves in the field and how to design pavements using these materials
- Both lab and field scale tests
  - variability in material properties
  - purity of materials
  - control of material quality and best construction practices
  - climatic effects and durability
  - Environemntal suitability

Project Tasks

Task I	*Structural capacity, long-term stability, design properties*
Task IA *Task IB* *Task IC* *Task ID*	*Literature Review* *Relationship between Mr and Composition of RCA or RAP* *Scaling and Equivalency: Specimen Tests to Field-Scale Conditions* *Climate Effects*
Task II	*Construction & Maintenance*
Task IIA *Task IIB*	*Compaction Level and Assessment* *Field Performance and Maintenance*
Task III	*Materials Control*
Task IV	*Leaching Characteristics*
Task V	*Extended Monitoring*
Task VI/VII	*Final Report & Dissemination*

Recycled Materials

Recycled Concrete Aggregate (RCA)



Objective of Today's Presentation

- To characterize the engineering properties of RCA as unbound road base without being treated or stabilized
- To assess the influence of
  - compaction effort
  - compaction moisture content
  - freeze-thaw cycling

  on the stiffness of RCA as unbound road base
- To determine the effect of varying RCA content on the stiffness of natural aggregates used as unbound road base

LITERATURE SURVEY

Typical RCA Properties

Physical Properties	
Specific Gravity	2.2 to 2.5 (Coarse Particles) 2.0 to 2.3 (Fine Particles)
Absorption	2% to 6% (Coarse Particles) 4% to 8% (Fine Particles)
Mechanical Properties	
LA Abrasion Loss	20% to 45% (Coarse Particles)
Magnesium Sulfate Soundness Loss	4% or Less (Coarse Particles) Less than 9% (Fine Particles)
California Bearing Ratio (CBR)	94% to 148%

FHWA Report FHWA-RD-97-148

Gradation

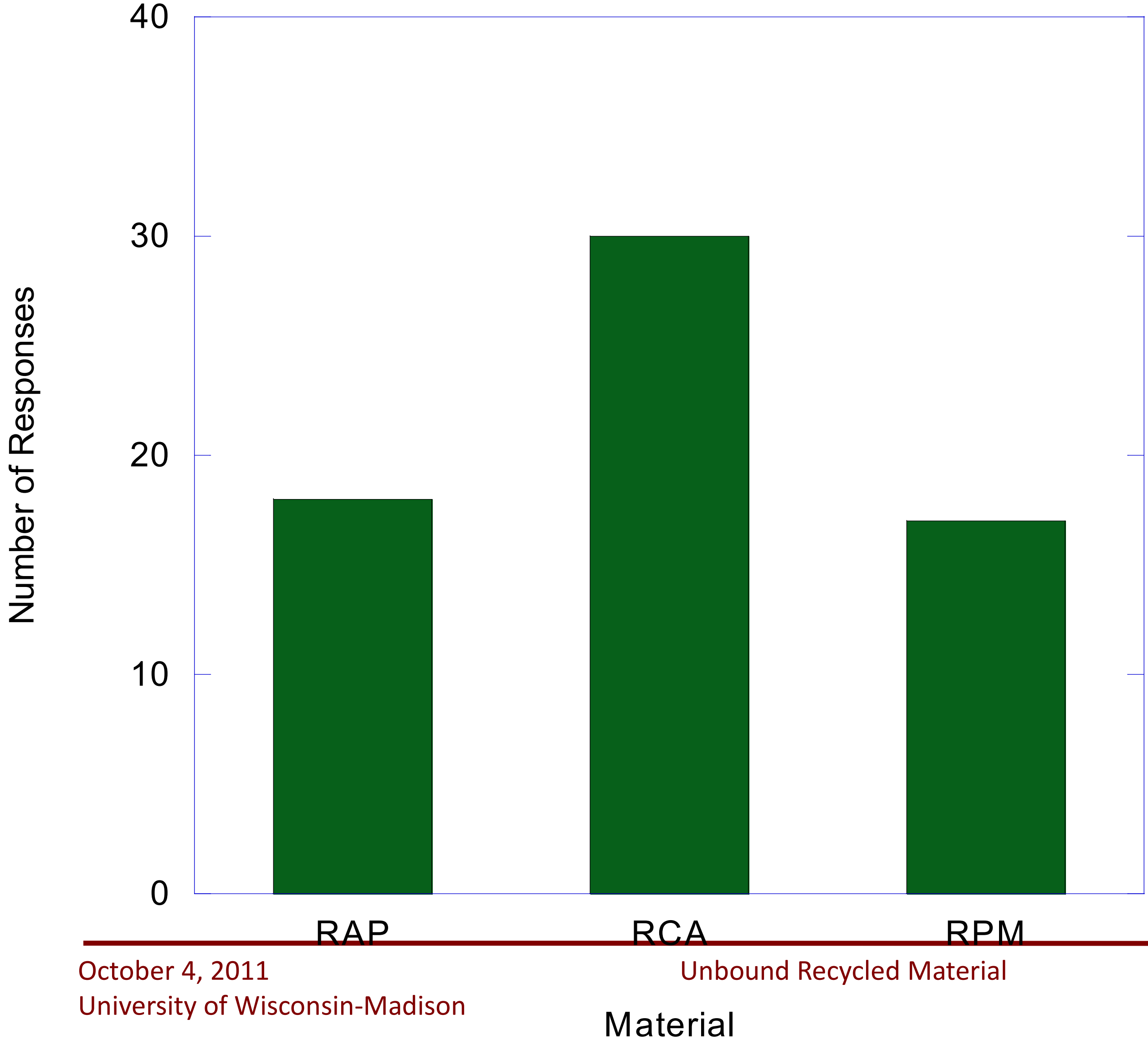
Material	% Finer	
	Fine (#200)	Coarse (19.1 mm)
Conventional Crushed Aggregate (MnDOT Class 5)	3 to 10%	90 to 100%
RAP	1 to 8% (Mean: 2.3%)	92 to 100% (Mean: 95.0%)
RPM	3 to 16 % (Mean: 8.0%)	93 to 96% (Mean: 95.8%)
RCA	3 to 8% (Mean: 5.1%)	50 to 100% (Mean:82.4 %)

RESULTS OF SURVEY BY RMRC 2009

The Usage, Storage and Testing of Recycled Materials

Material Use and Storage

Which of the following recycled materials do you use as a granular base course?

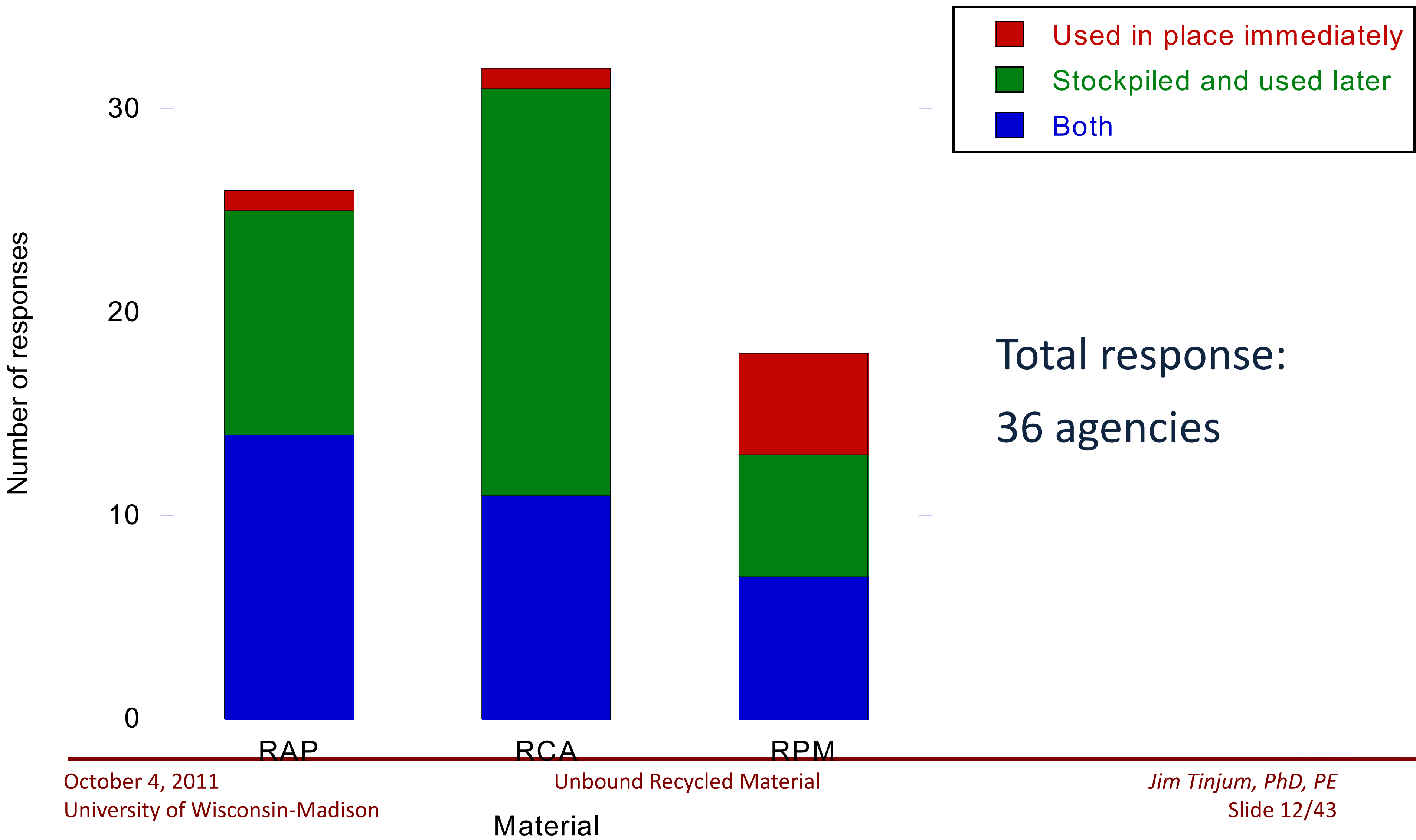


34 Total responses

- RAP: 18 (53%)*
- RCA: 30 (88%)*
- RPM: 17 (50%)*

* More than one response possible

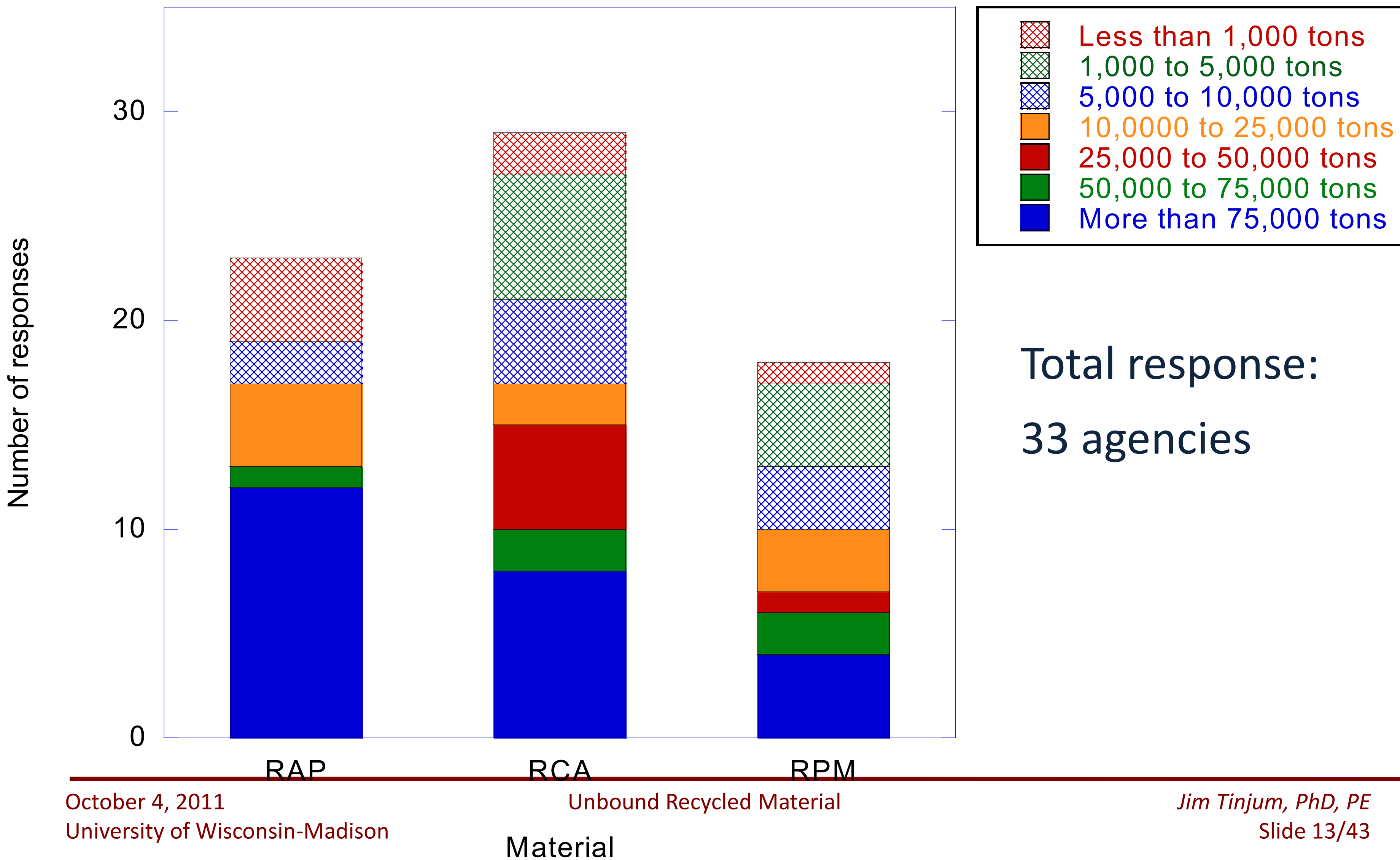
When are the recycled materials used?



Total response:

36 agencies

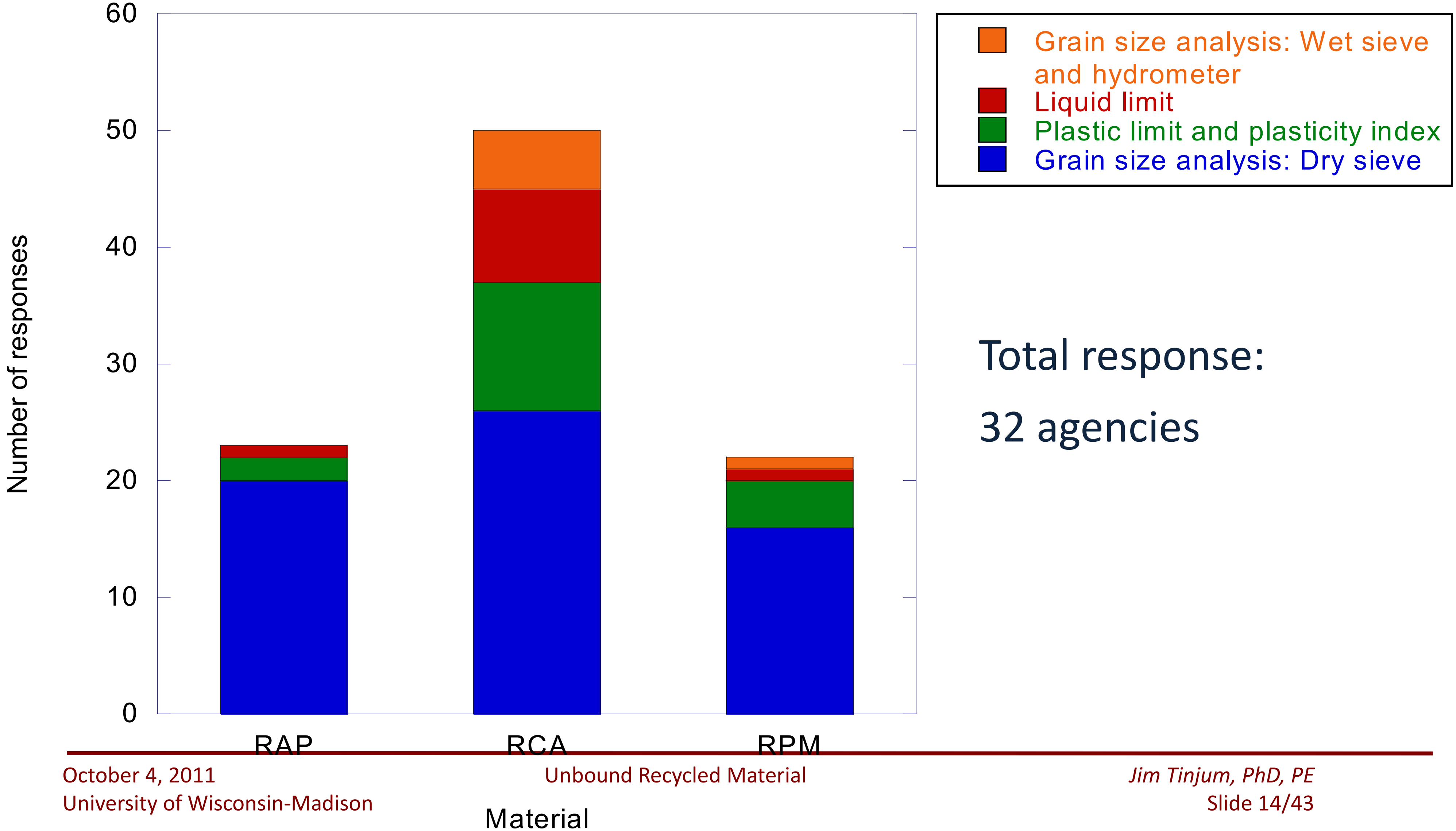
In a given year, how much of the recycled material do you use?



Total response:

33 agencies

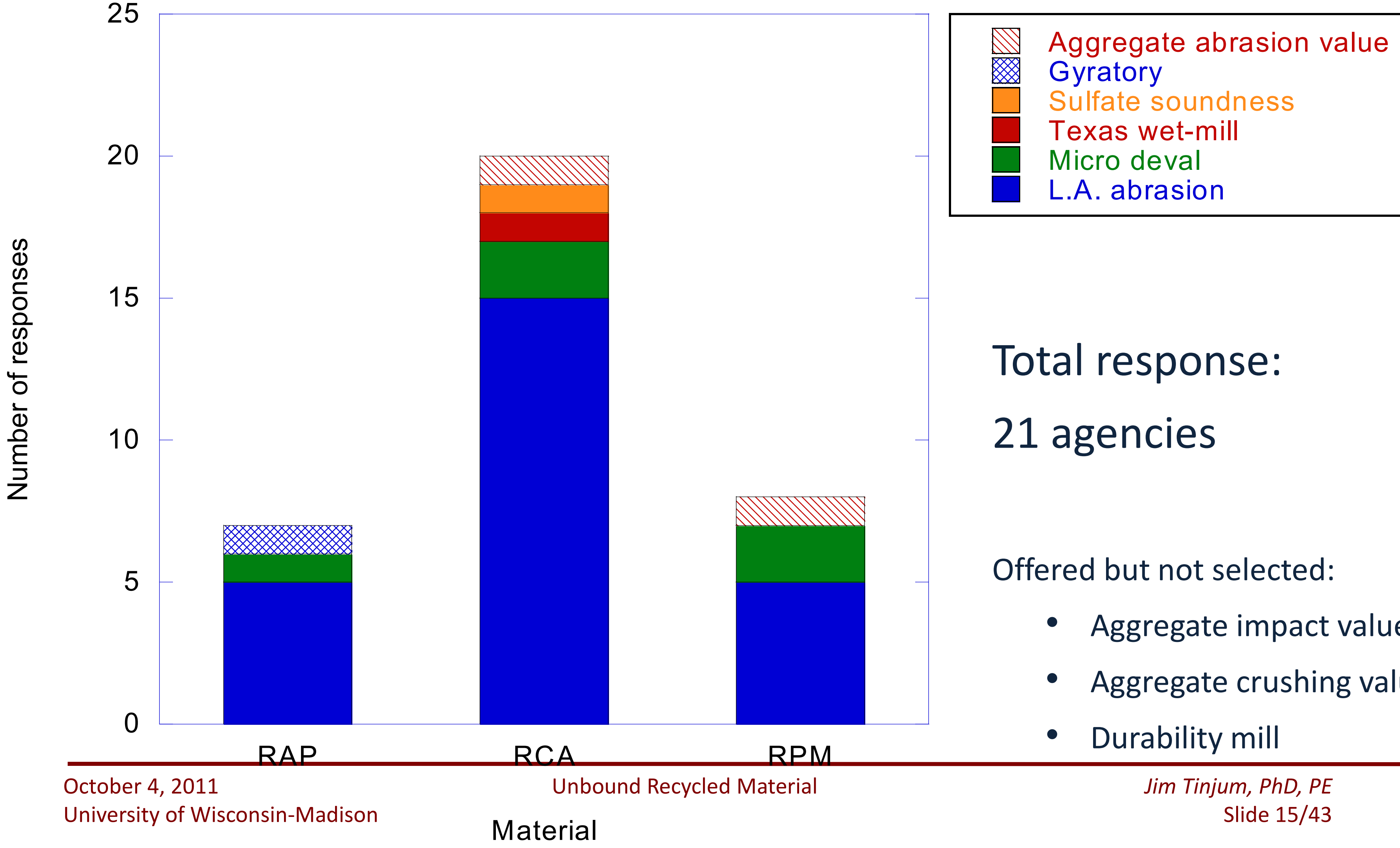
Are any of the following tests used in specifications for the material?



Total response:

32 agencies

Which of the following aggregate quality tests for <u>toughness</u> do you perform on the material prior to placement?



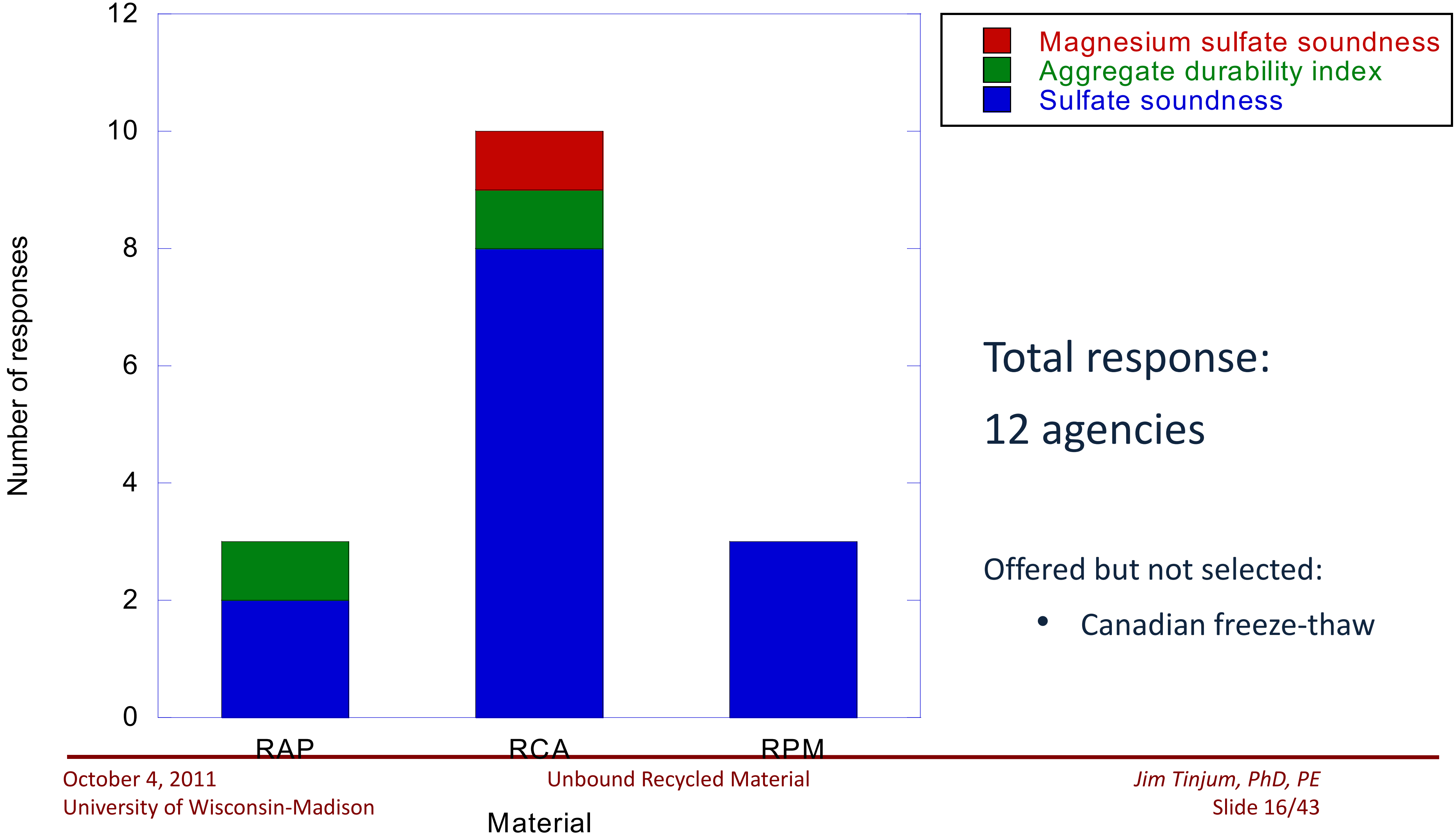
Total response:

21 agencies

Offered but not selected:

- Aggregate impact value
- Aggregate crushing value
- Durability mill

Which of the following aggregate quality tests for durability do you perform on the material prior to placement?



Total response:

12 agencies

Offered but not selected:

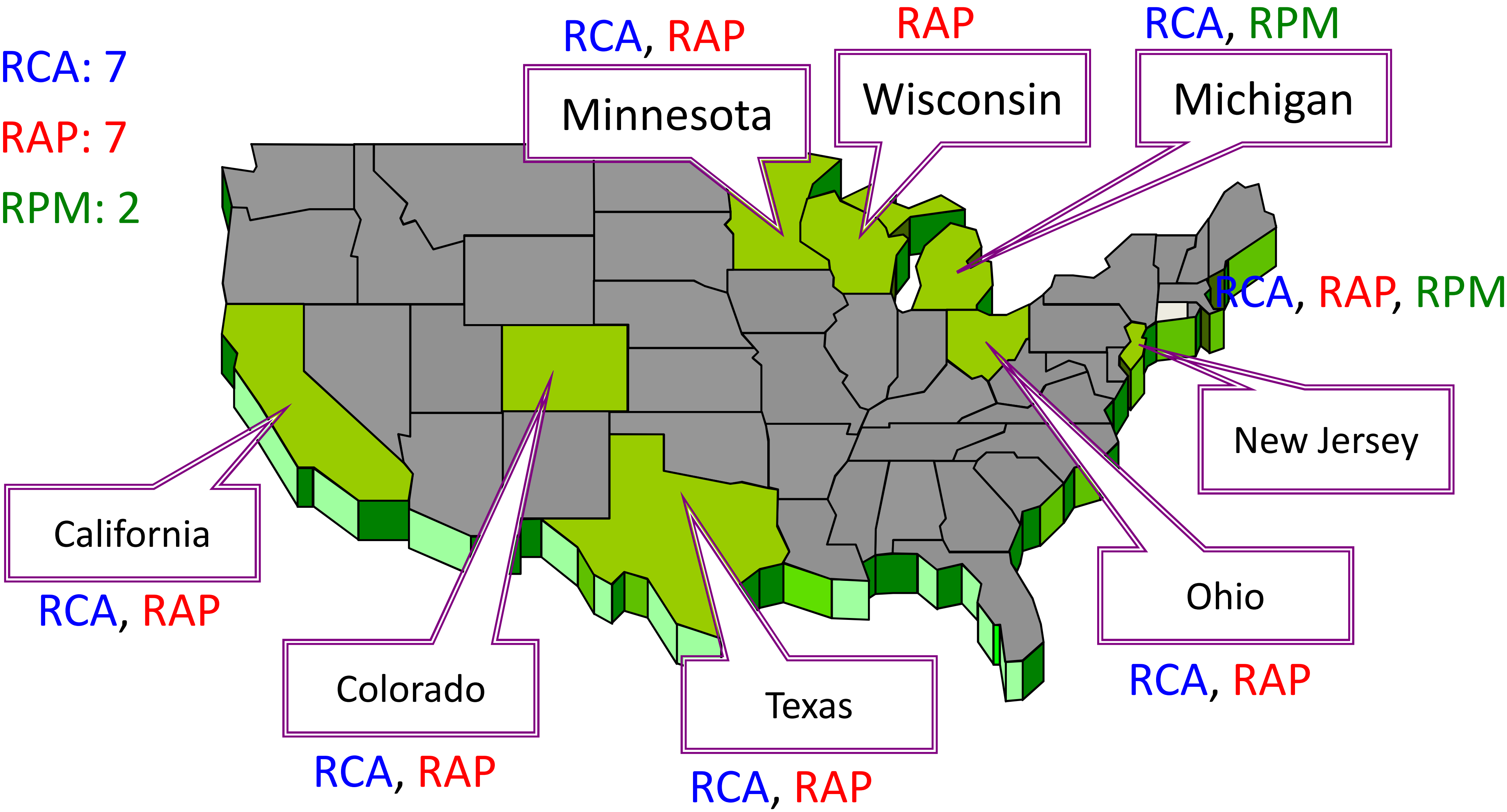
- Canadian freeze-thaw

Materials

RCA: 7

RAP: 7

RPM: 2

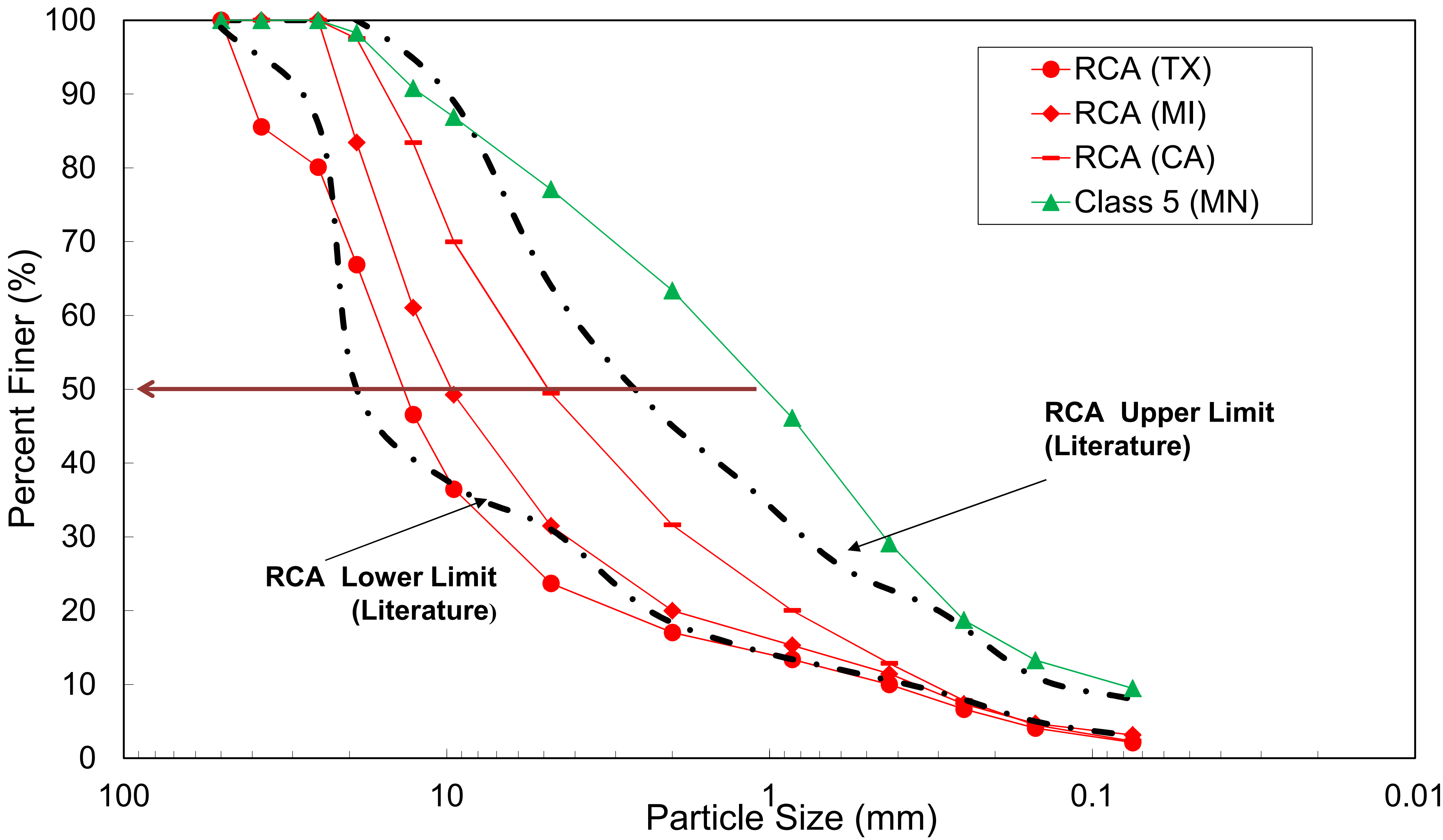


Representative Materials

Gradation	RCA
Coarser	Texas
Medium	Michigan
Finer	California

- Class 5 (Natural Aggregate)

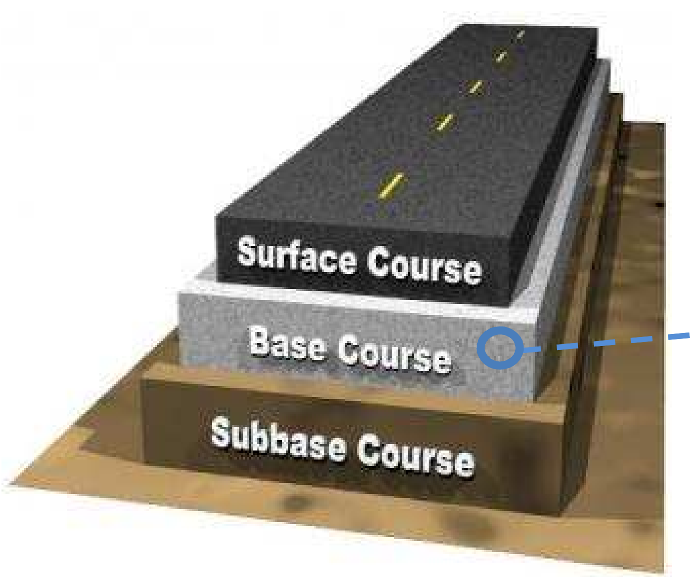
Gradation: RCAs and Class 5



Test Method

- Resilient Modulus (M_r) Test

$$M_r = \sigma_d / \varepsilon_r$$

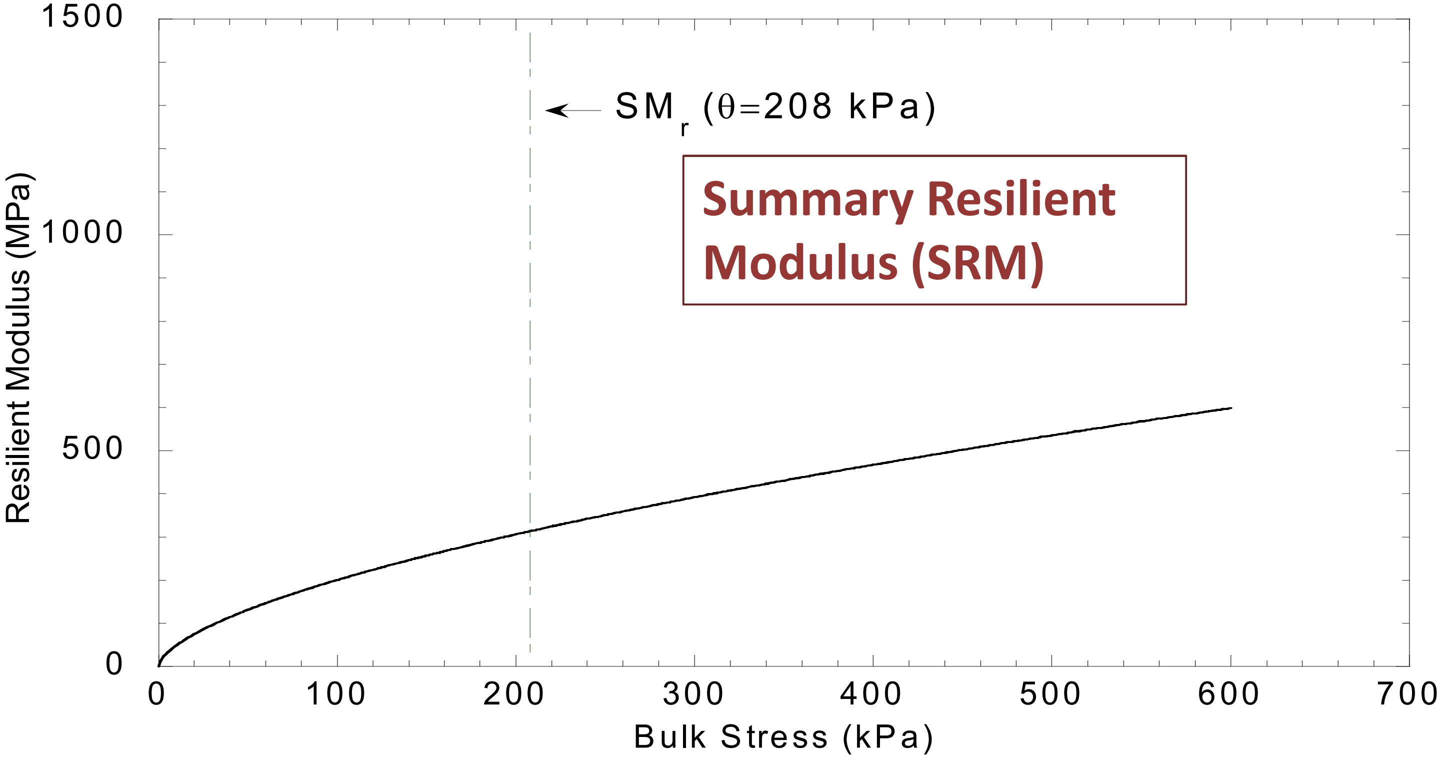


where σ_d = deviator stress, ε_r = recoverable elastic strain

Resilient Modulus

Power Function: $$M_r = k_1 \theta^{k_2}$$ where θ = bulk stress

k_1 and k_2 = fitting parameters



Freeze-Thaw Cycling

TE1

Freeze-Thaw Cycling

- Specimens
  - Prepared in the same manner as resilient modulus specimens
  - Retained in the freezer for 24 hours
  - Thawed at room temperature for 24 hours

- After the last cycle, specimens were extruded frozen and thawed inside the resilient modulus cell
- Specimens were subjected to 5, 10, 20 cycles

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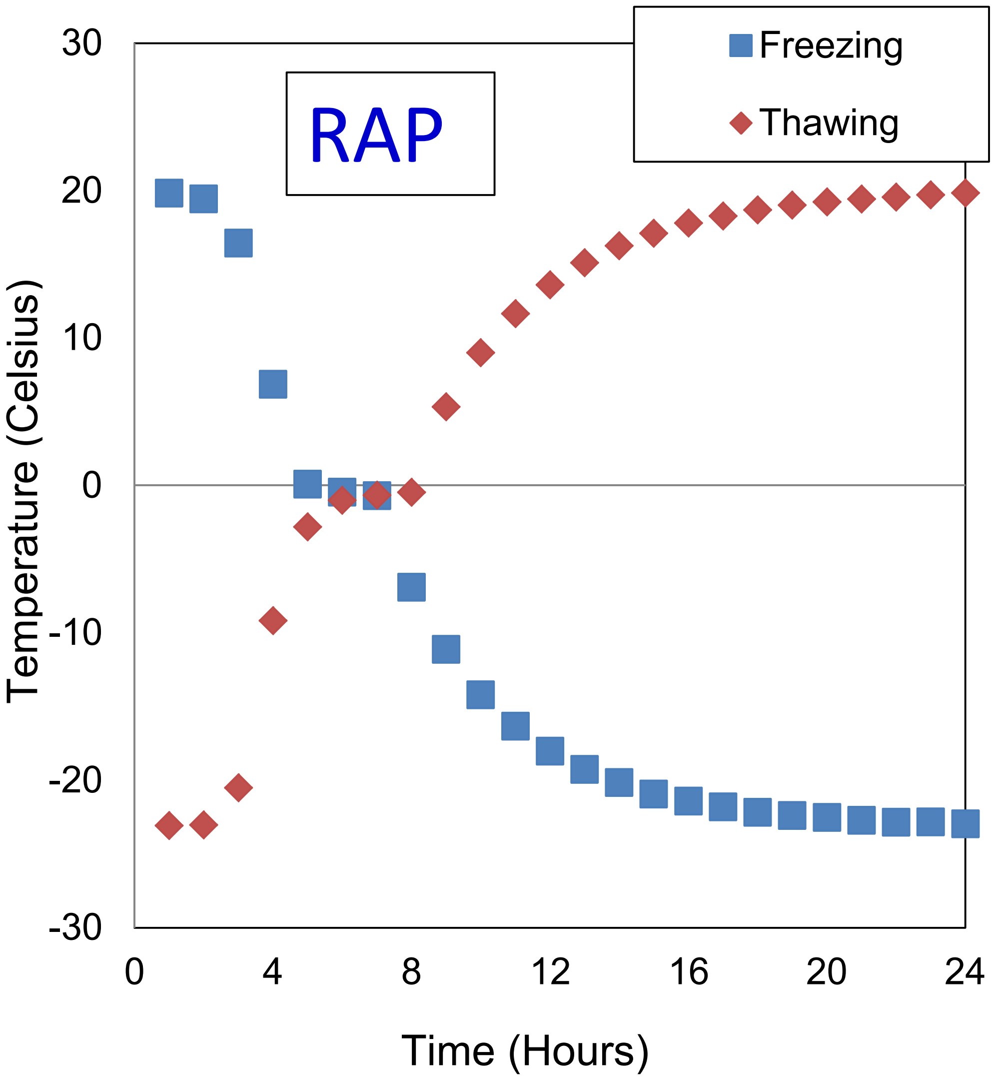
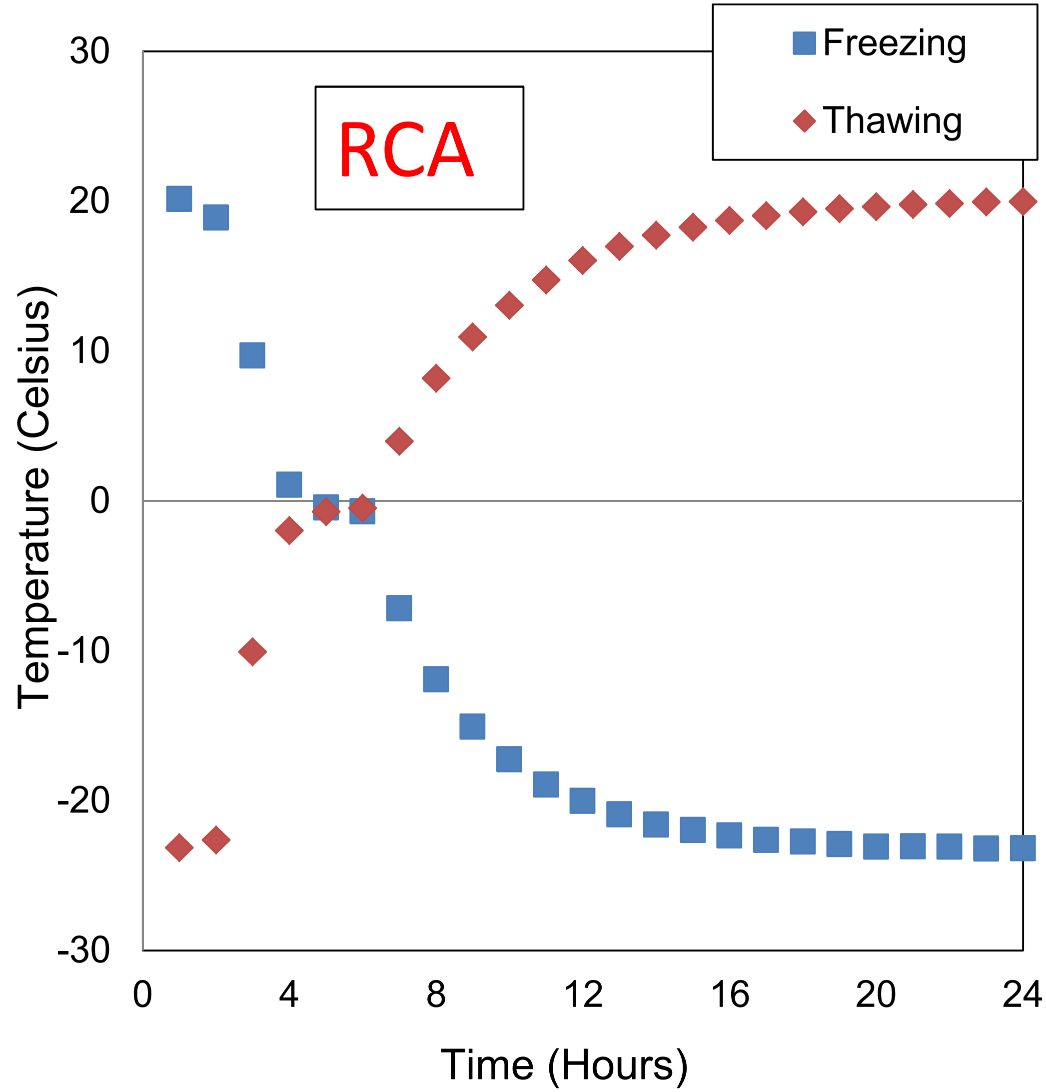
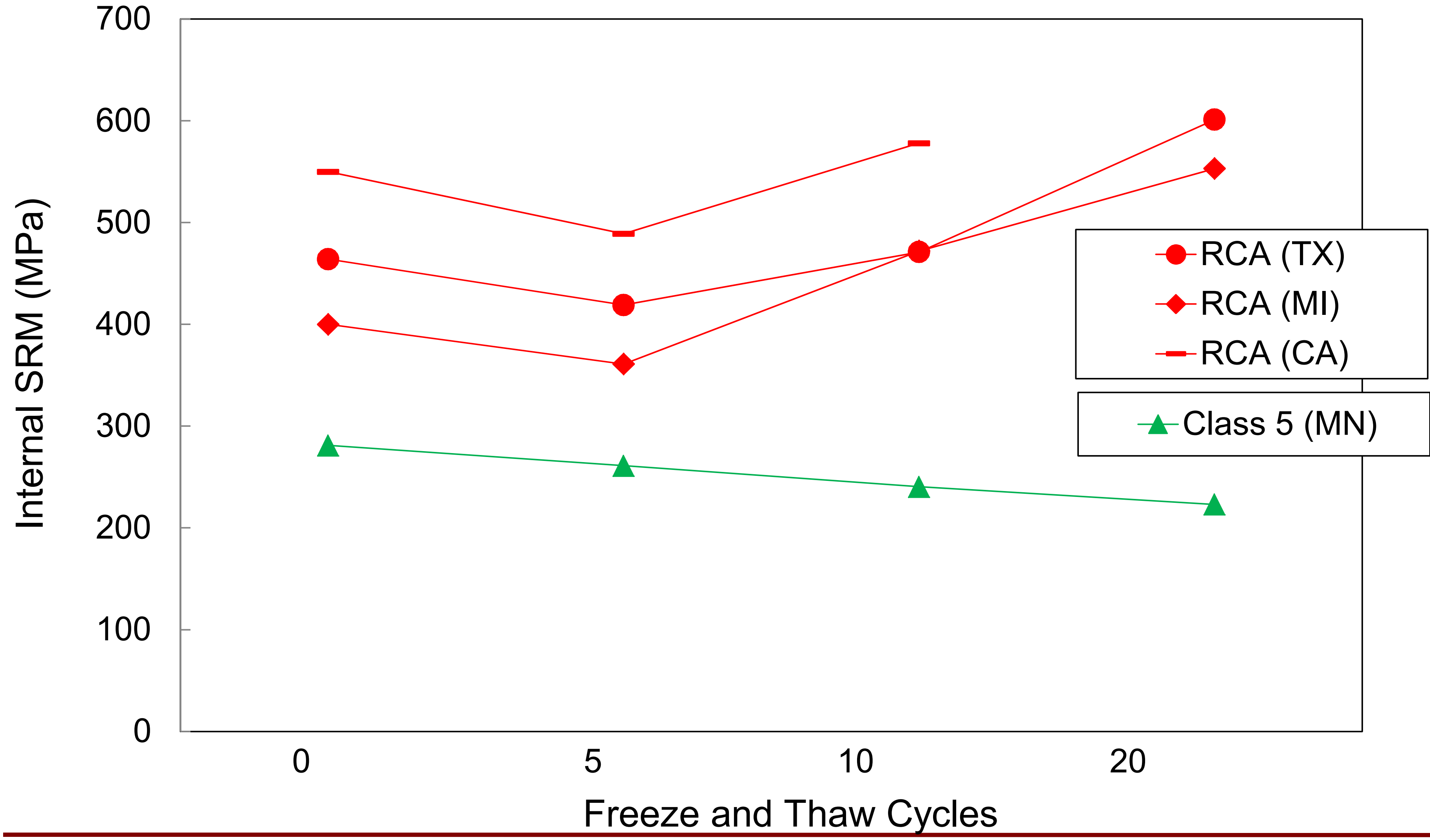
Temperature Records for RAPs and RCAs

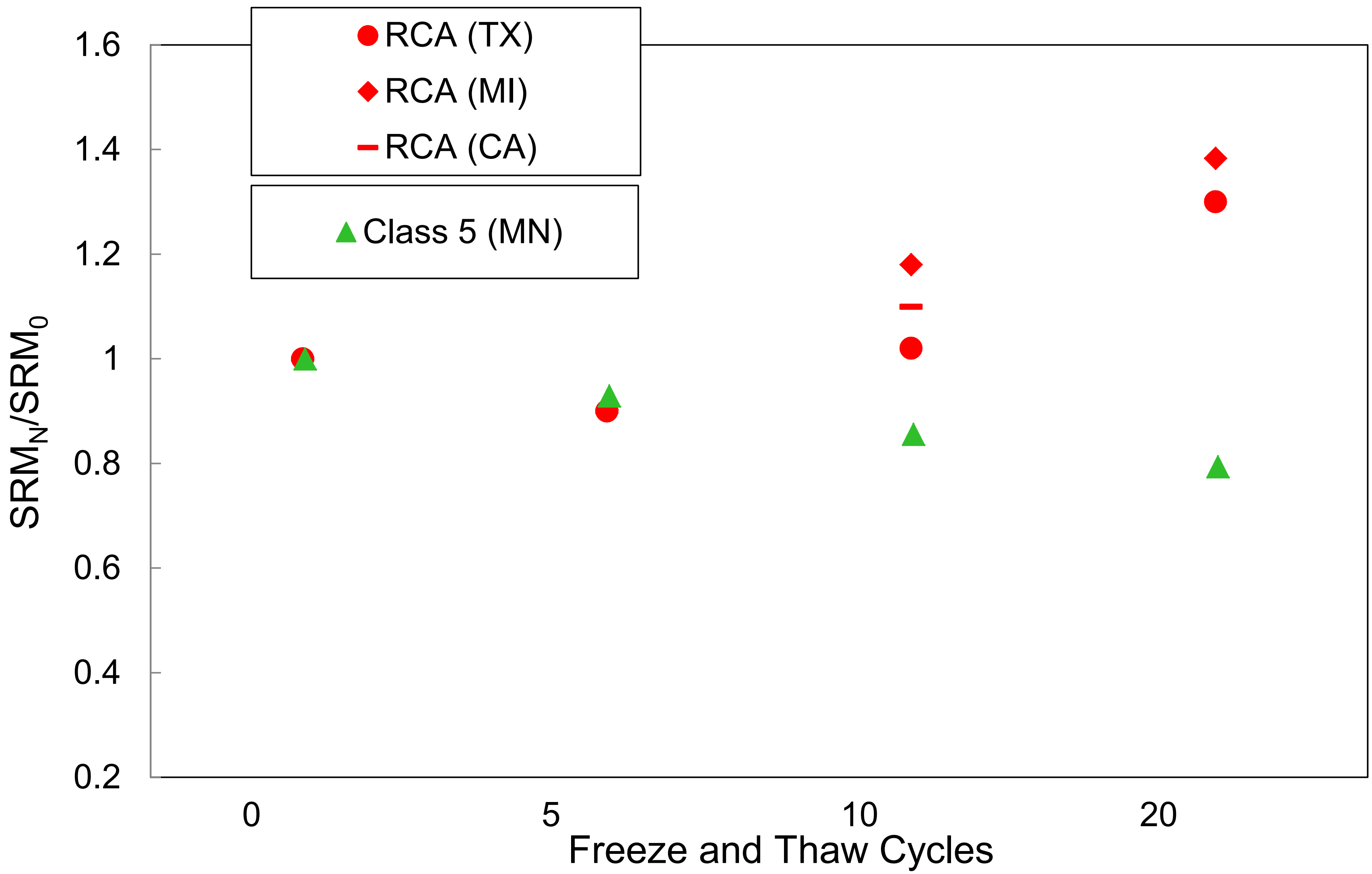




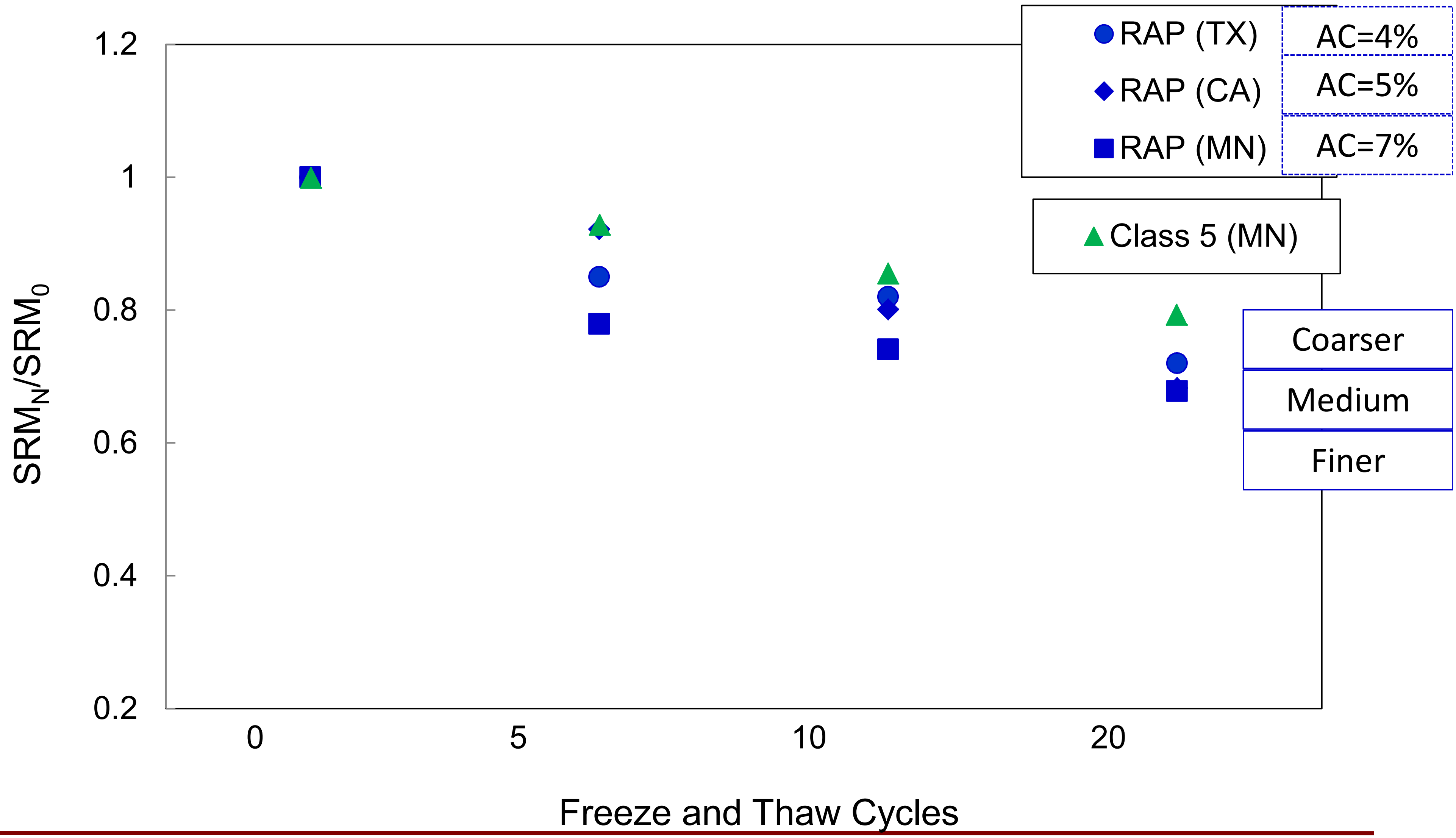
RCAs: SRM vs F-T Cycles



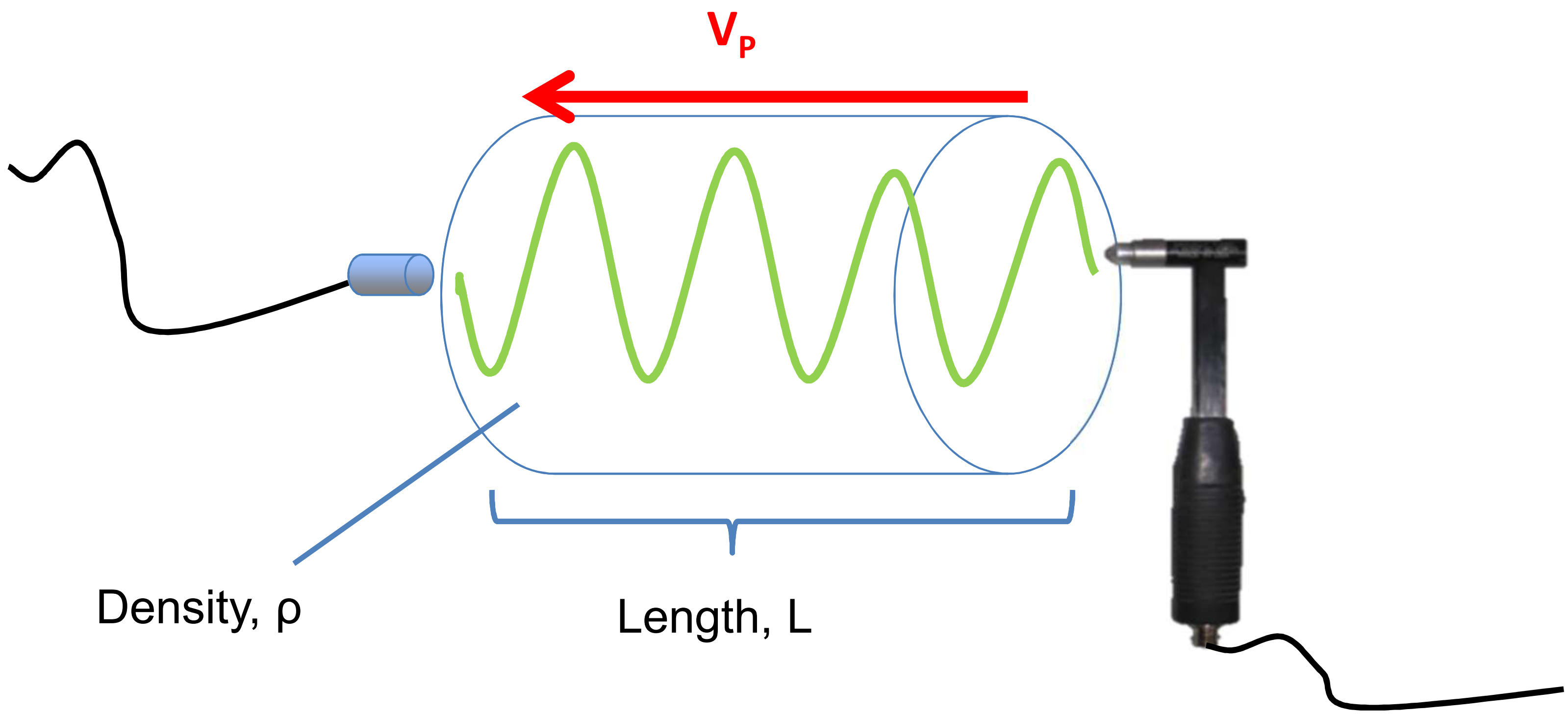
RCAs: Normalized SRM vs F-T Cycles



RAPs: Normalized SRM vs F-T Cycles



Verification of RCA Behavior with Seismic Modulus Test



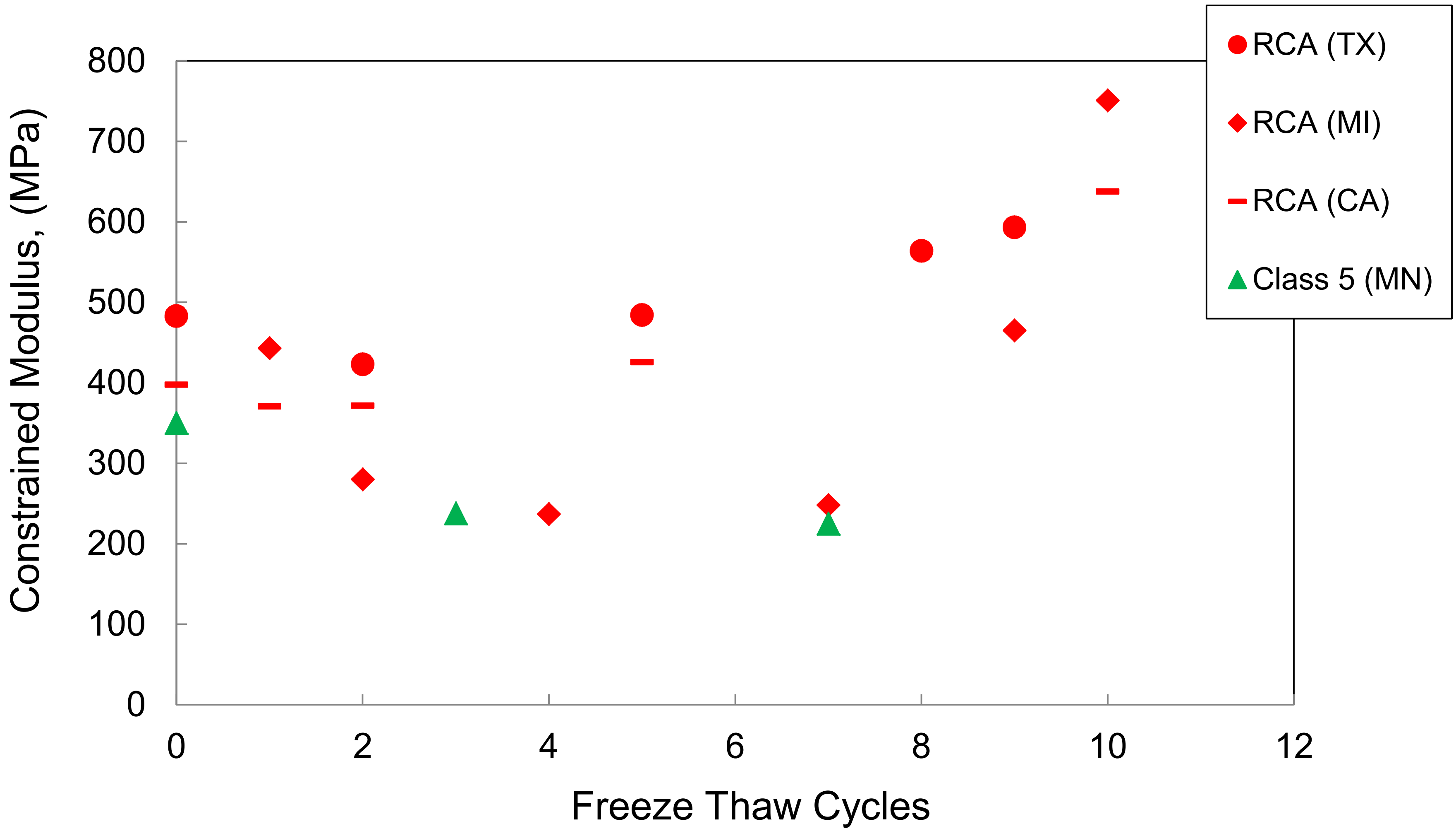
P- Wave Velocity

$$V_p = \frac{L}{t_2 - t_1}$$

Constrained Modulus

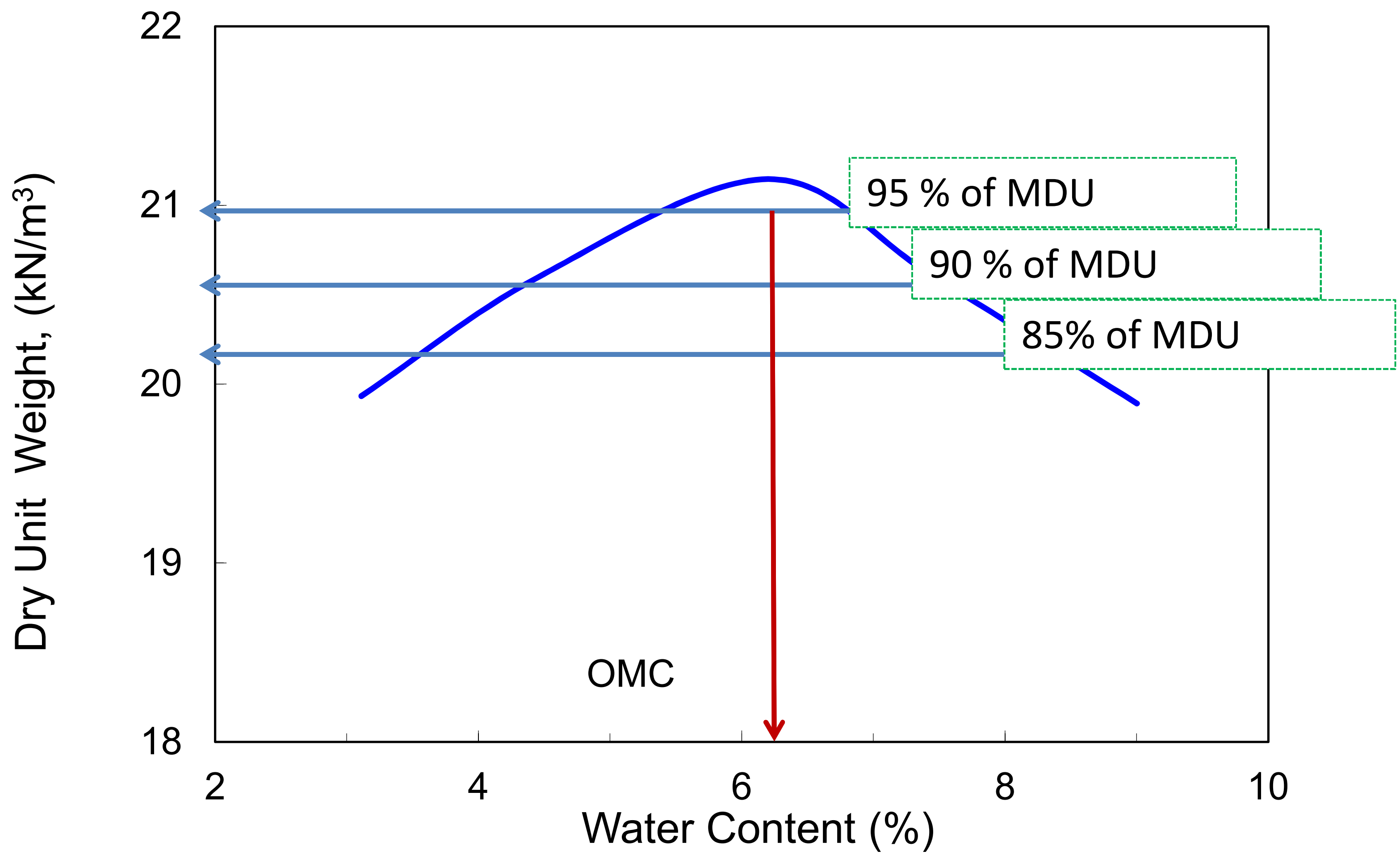
$$\mathbf{M} = {V_p}^2 * \rho$$

RCAs: Constrained Modulus vs F-T Cycles

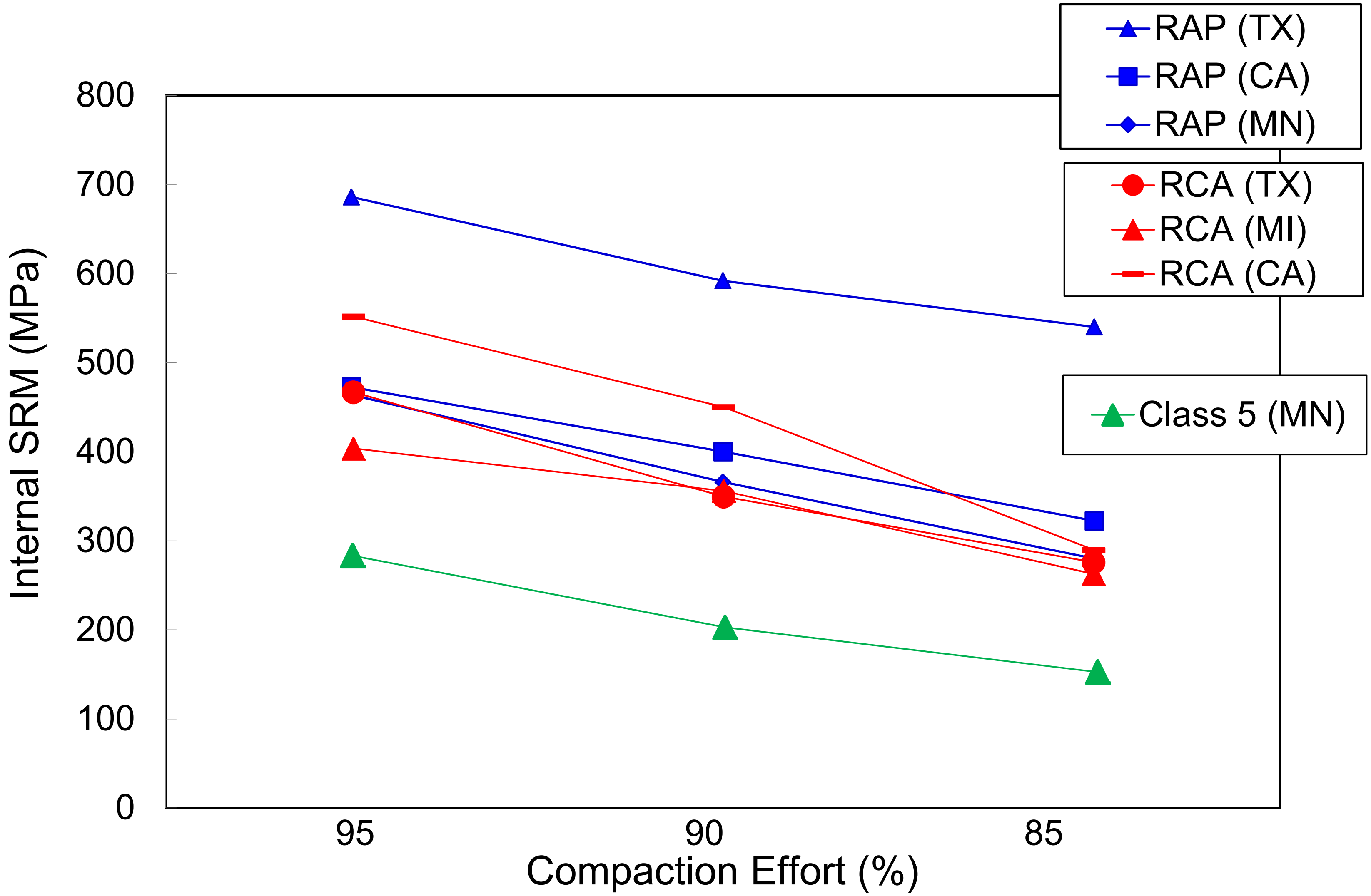


Compaction Conditions
Effect of Density (Compaction Effort) and Compaction Moisture on Modulus

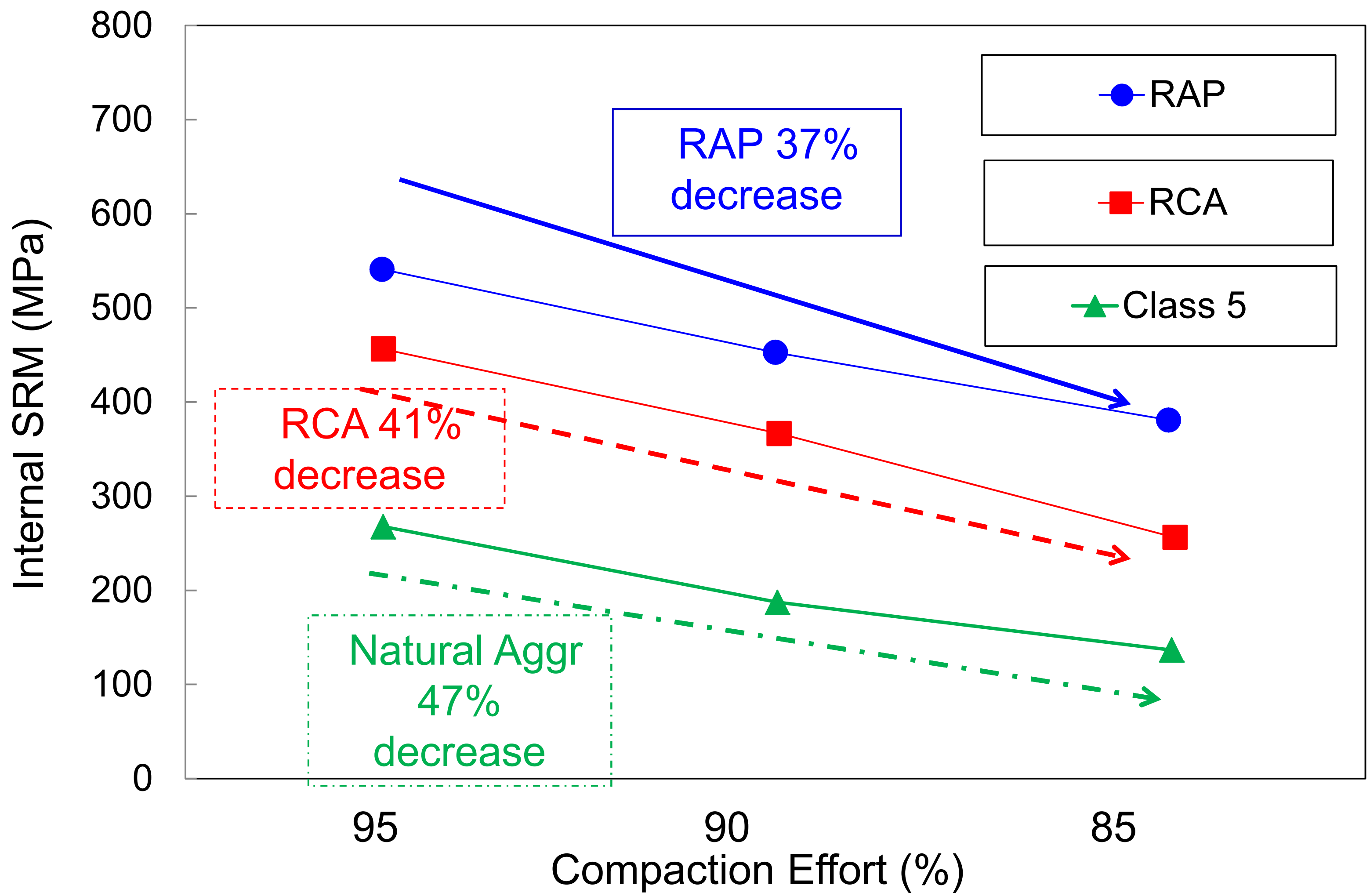
Density (Relative Compaction) Effect



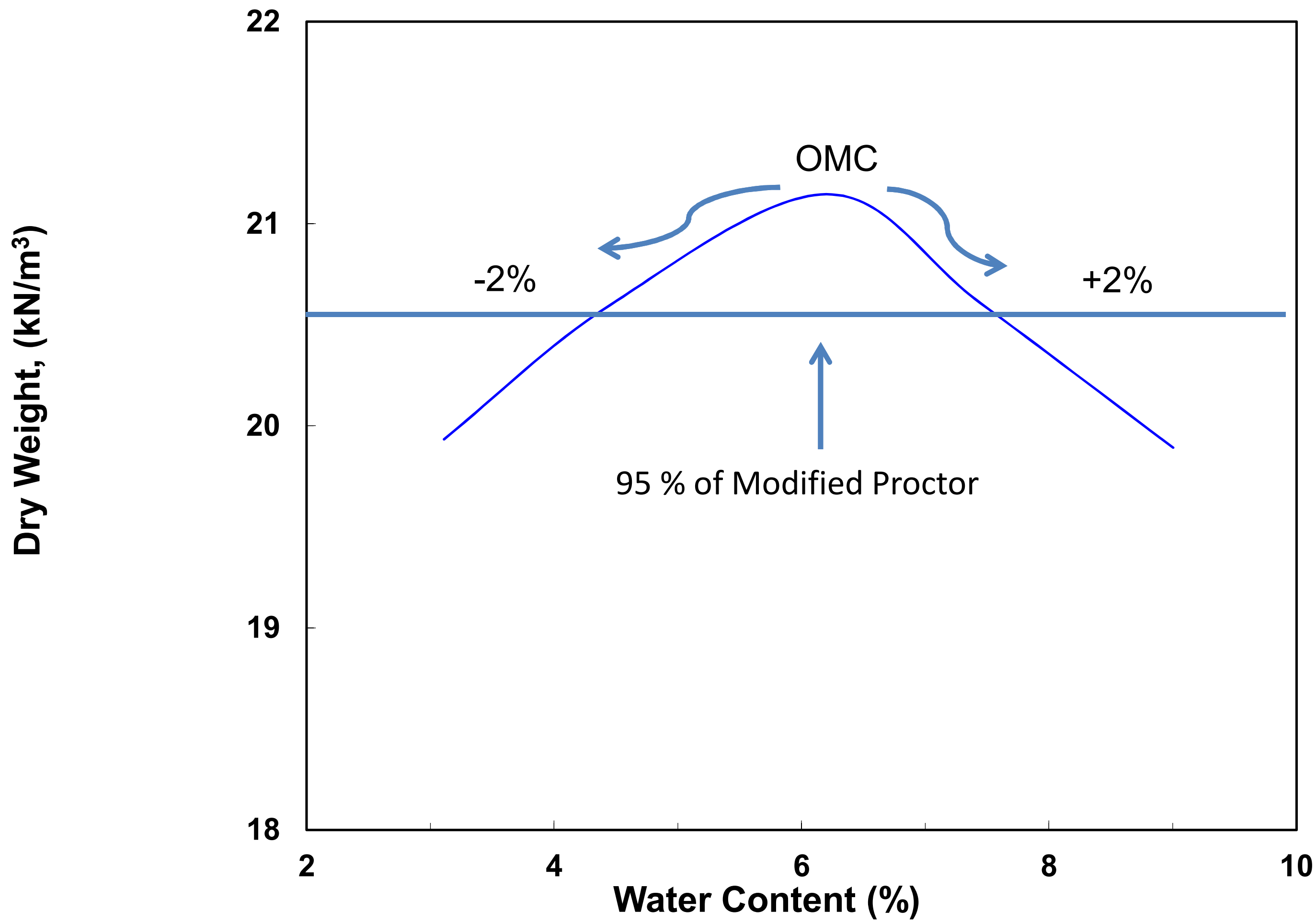
Effect of Relative Compaction on Modulus



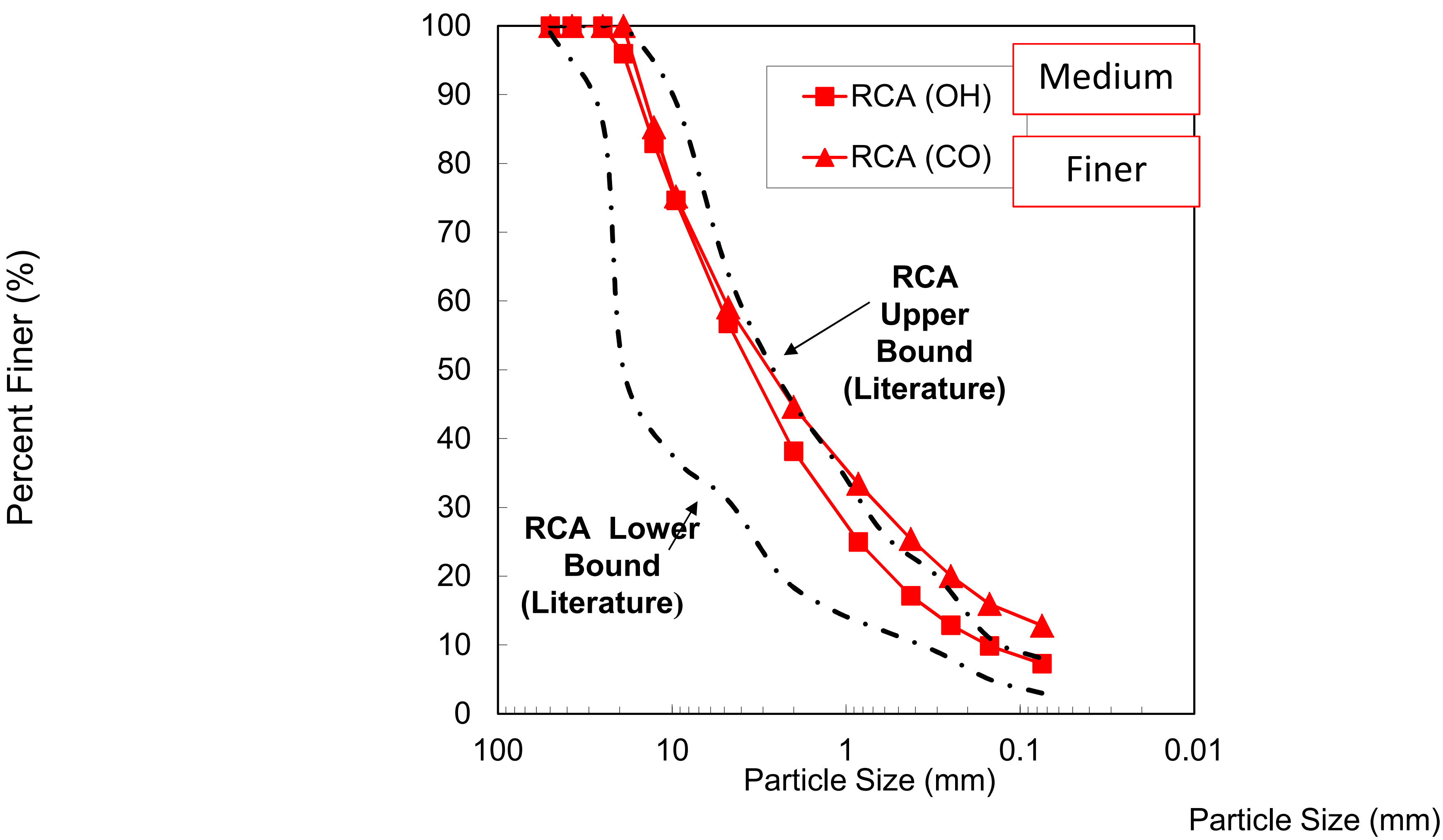
Summary Effect of Relative Compaction on Modulus



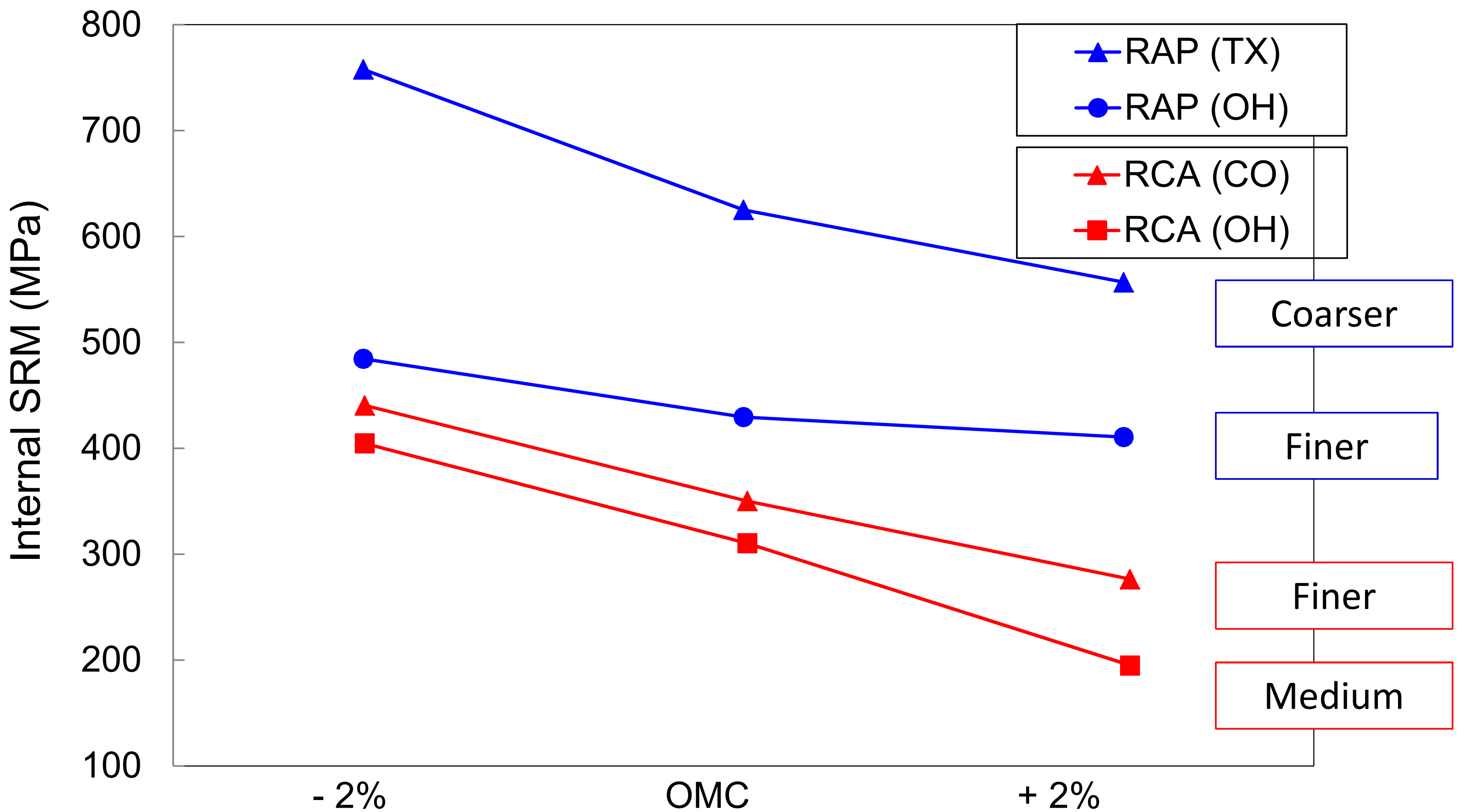
Compaction Moisture Effect



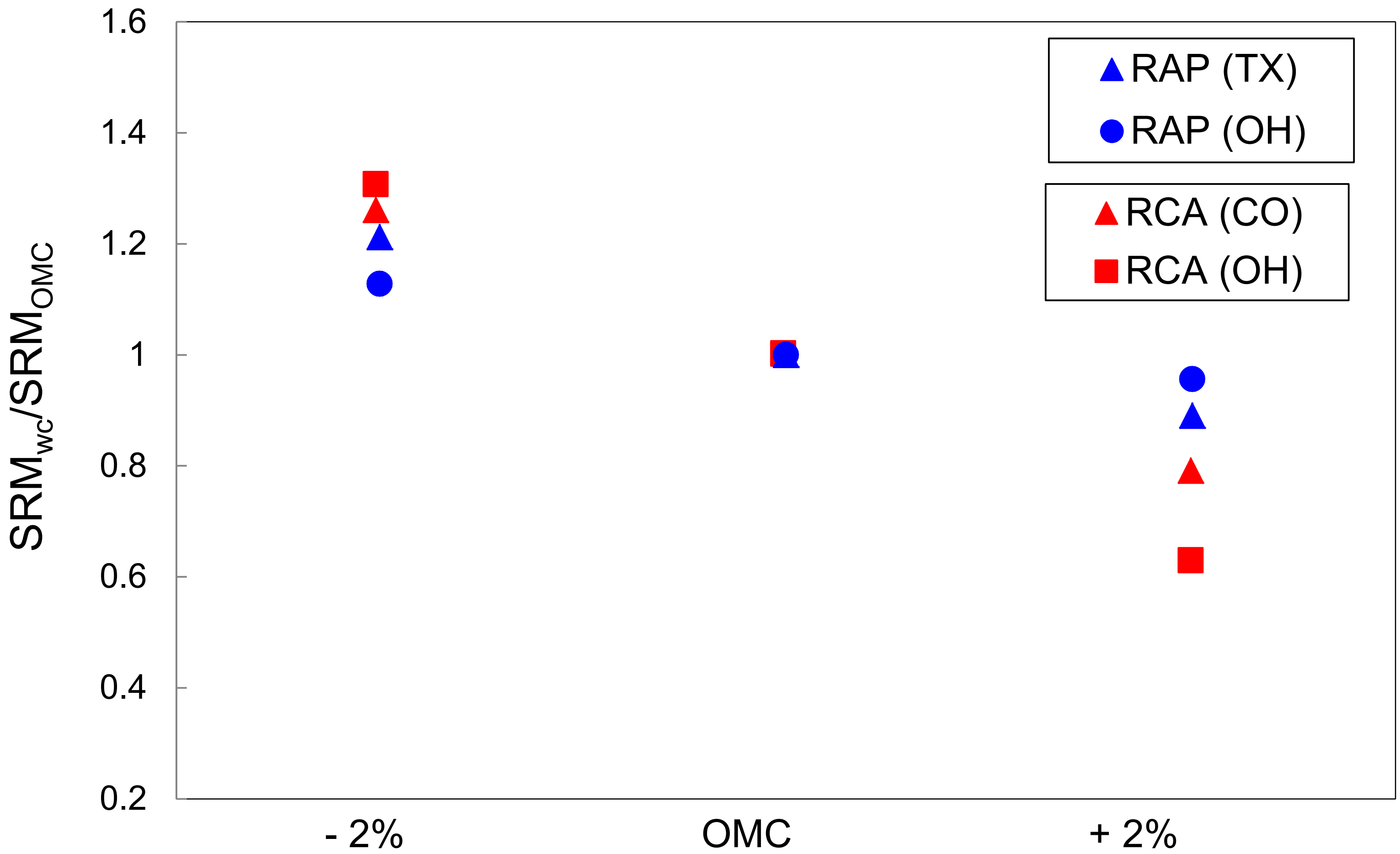
PSDs of RAPs and RCAs Used in Moisture Effects Testing



Effect of Compaction Moisture on Modulus



Effect of Compaction Moisture on Normalized SRM



Summary of Compaction Moisture Effect on Normalized Modulus

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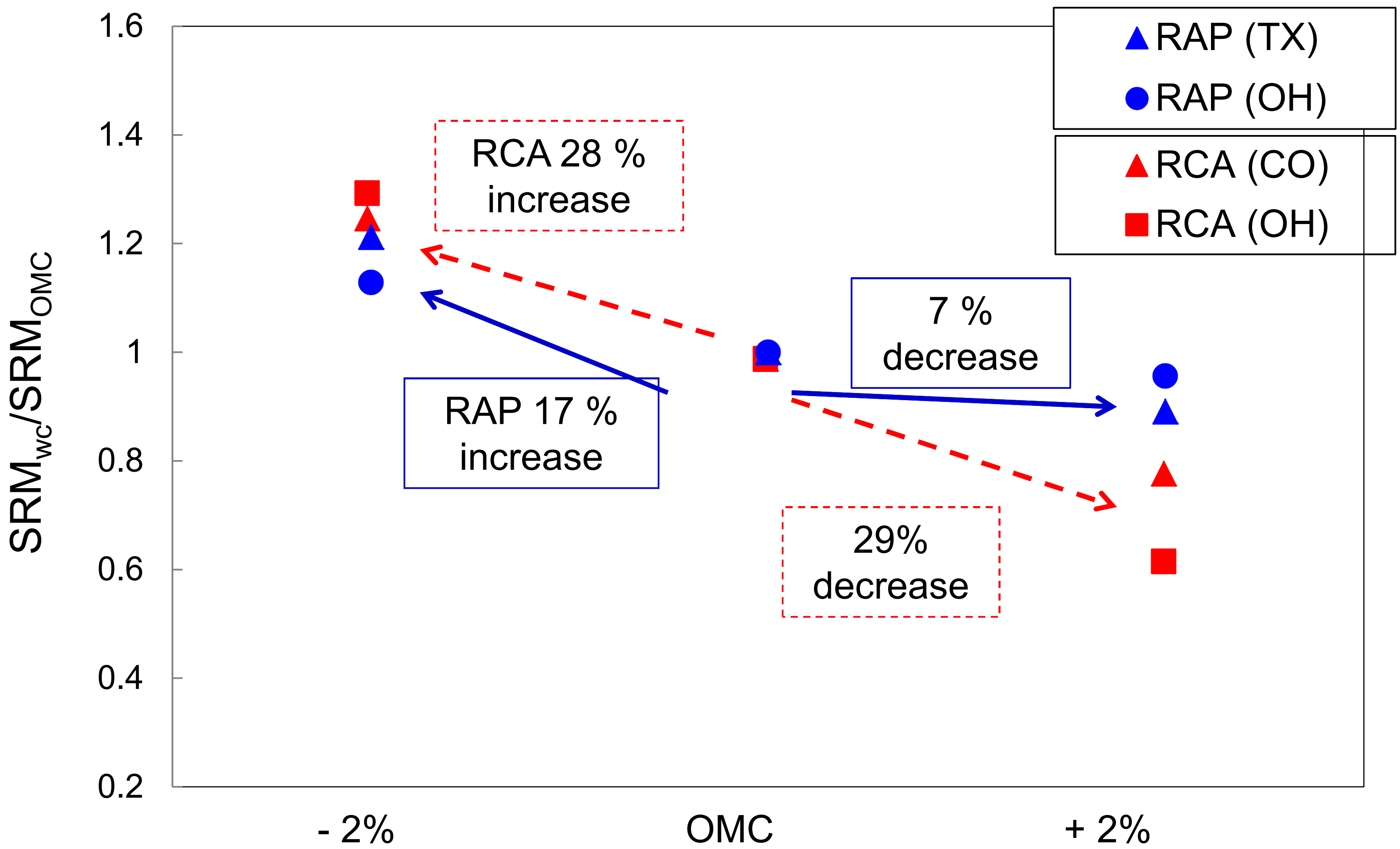

Slide 38

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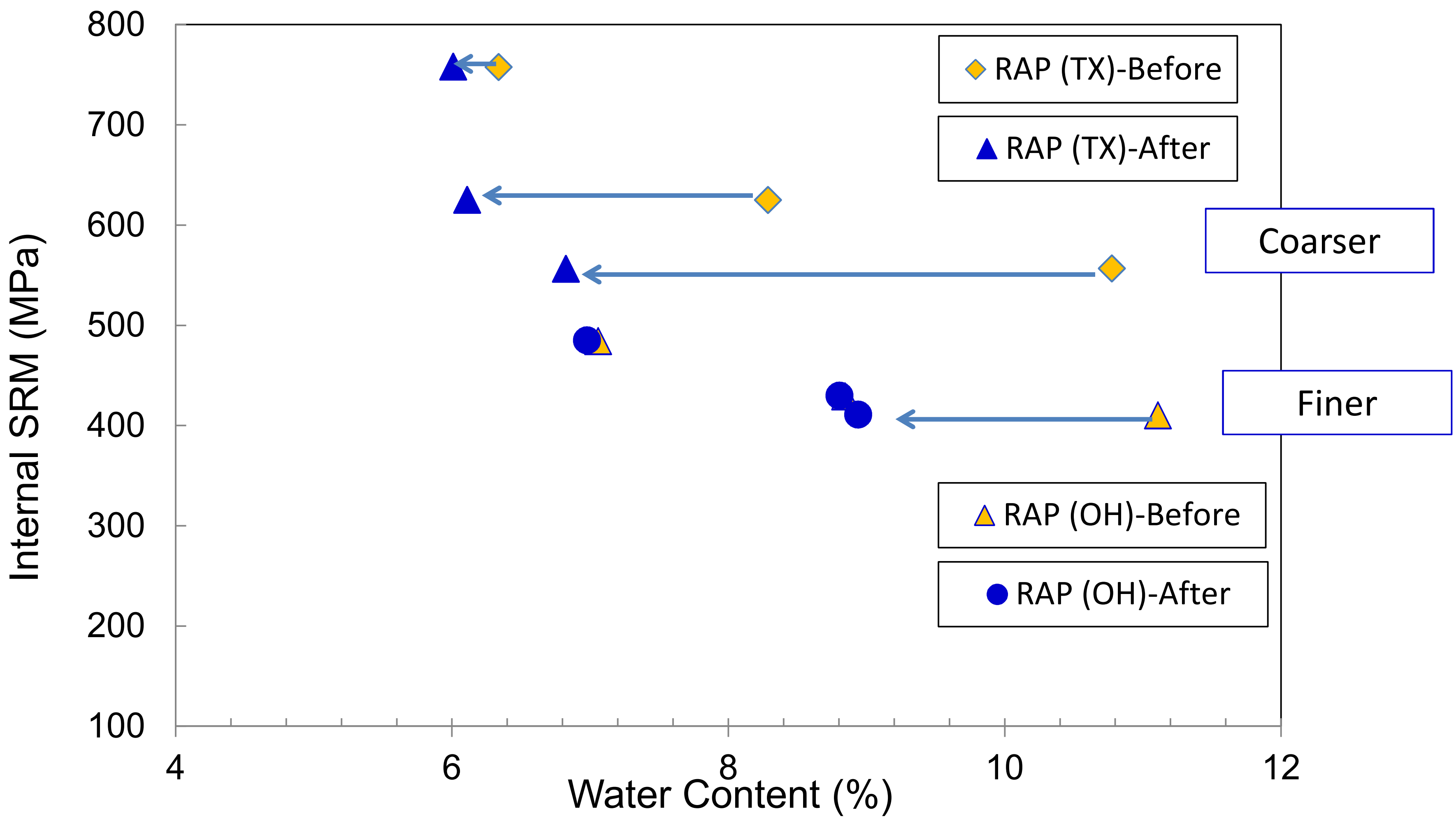
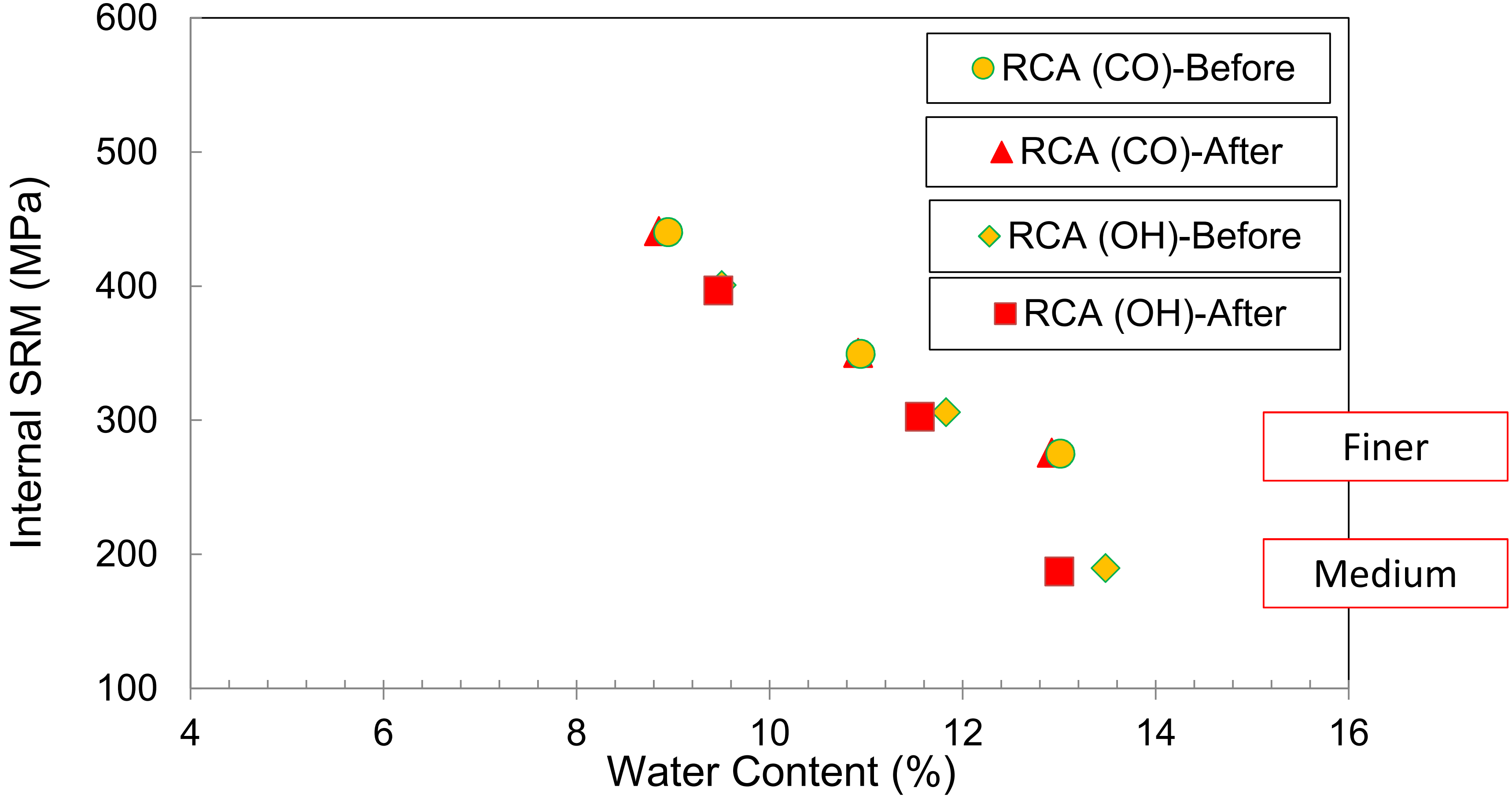
bozyurt, 8/2/2011

Moisture Content Before and After Test



RCA: Effect of Compaction Moisture on Modulus

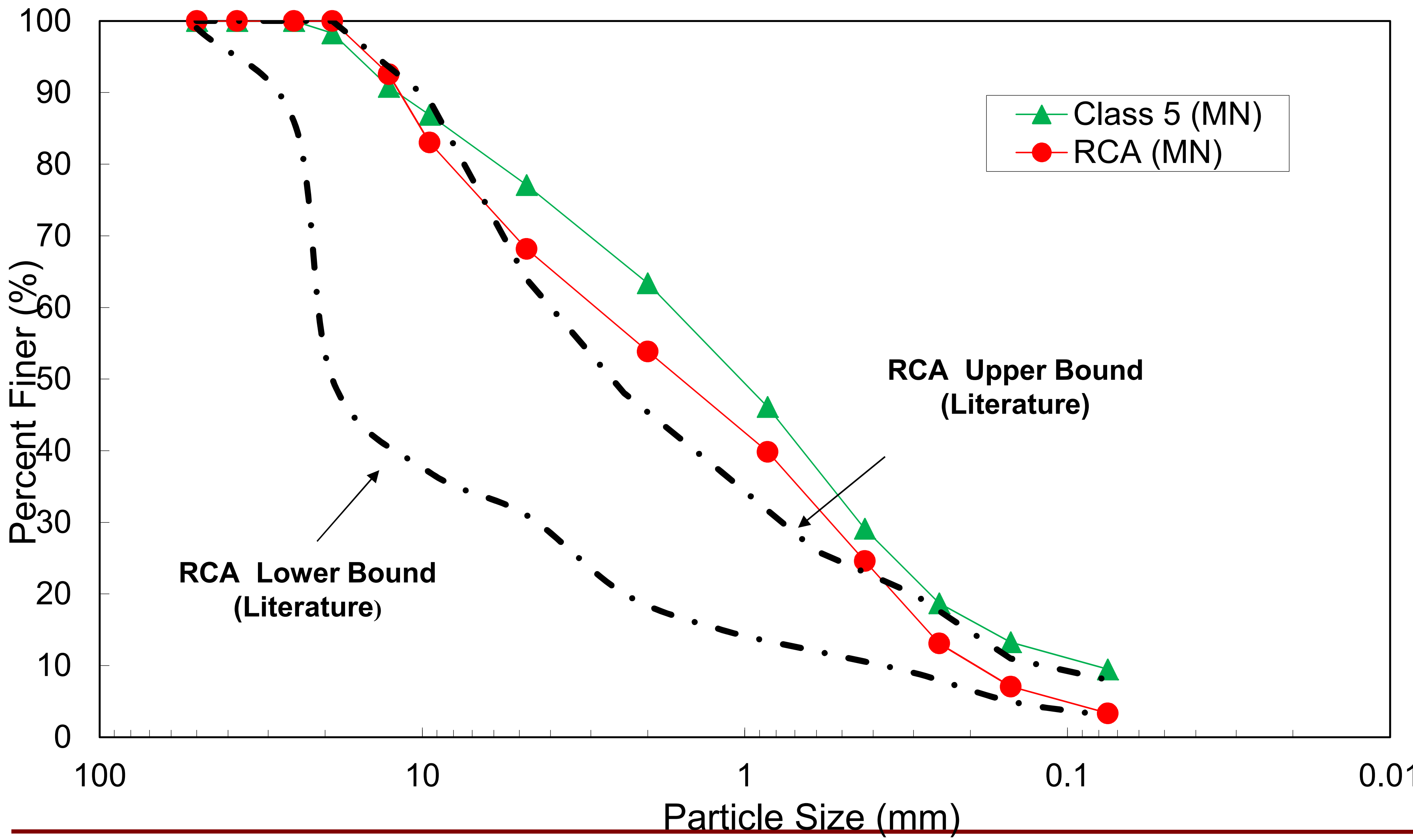


Effect of RAP or RCA Content on Stiffness of Natural Aggregate Blends

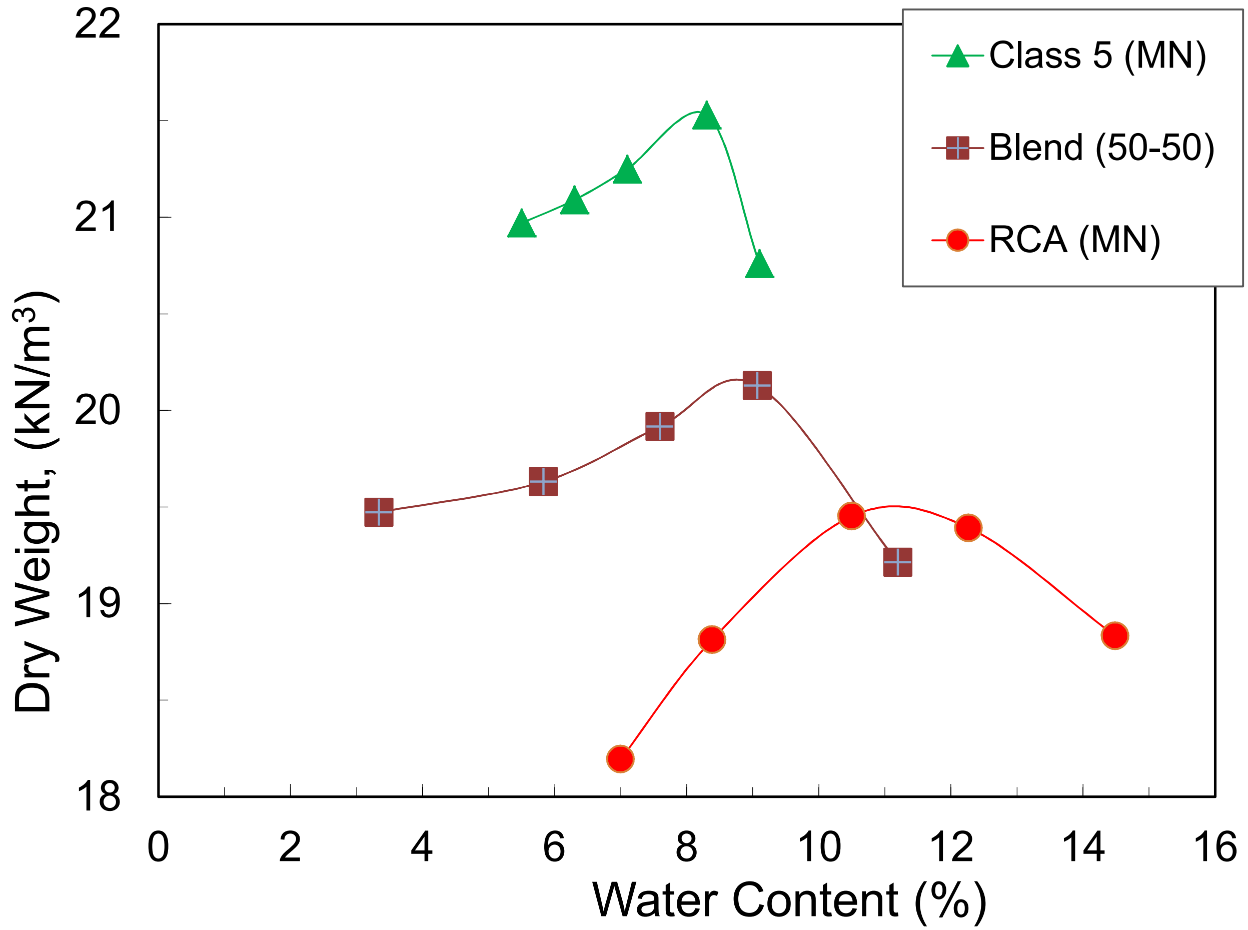
Materials Selected for Blends

RCA	Natural Aggregate
Minnesota	Minnesota (Class 5)

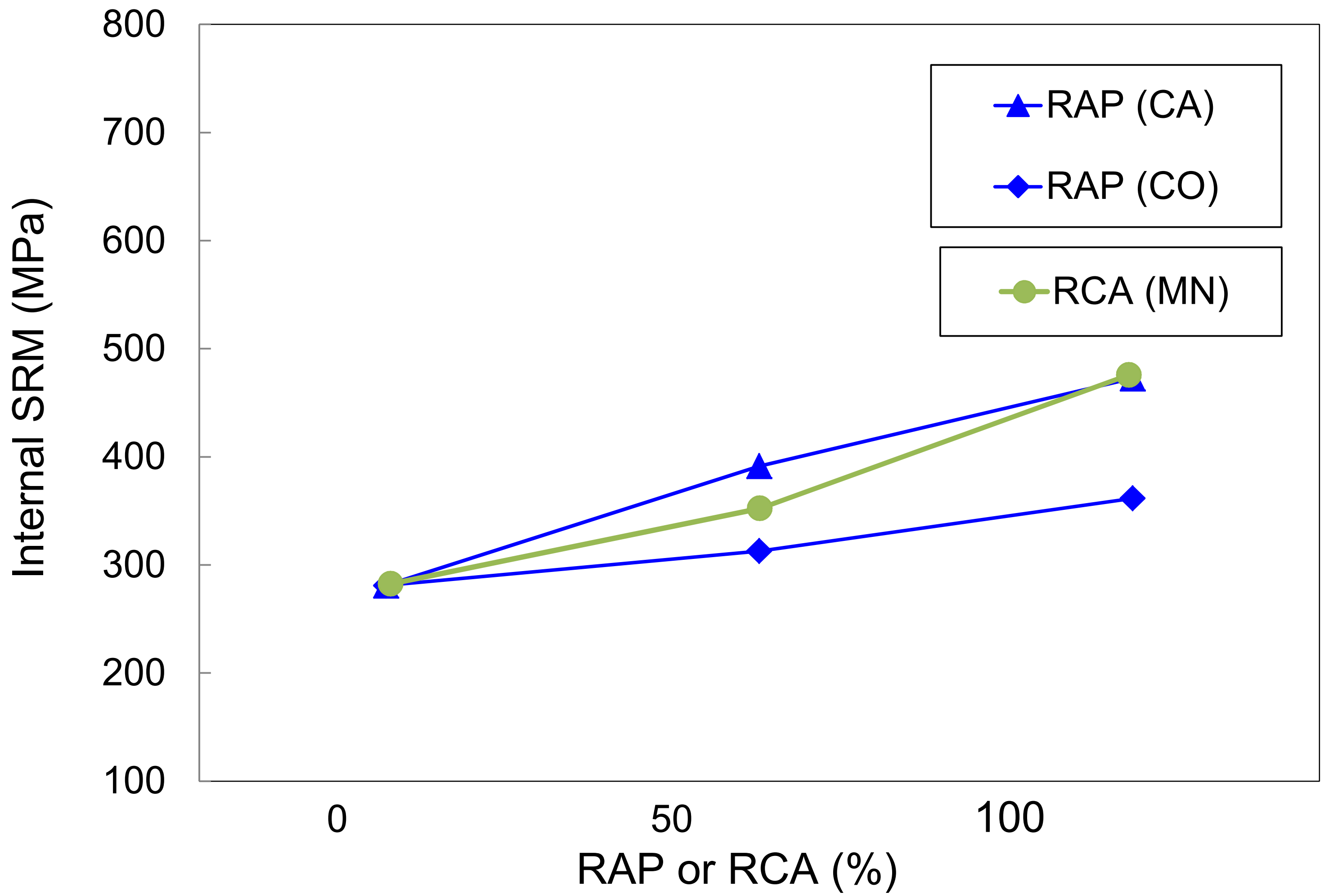
PSD of RCA (MN) and Class 5 Used in Blends



Compaction Curve: RCA (MN) Blend

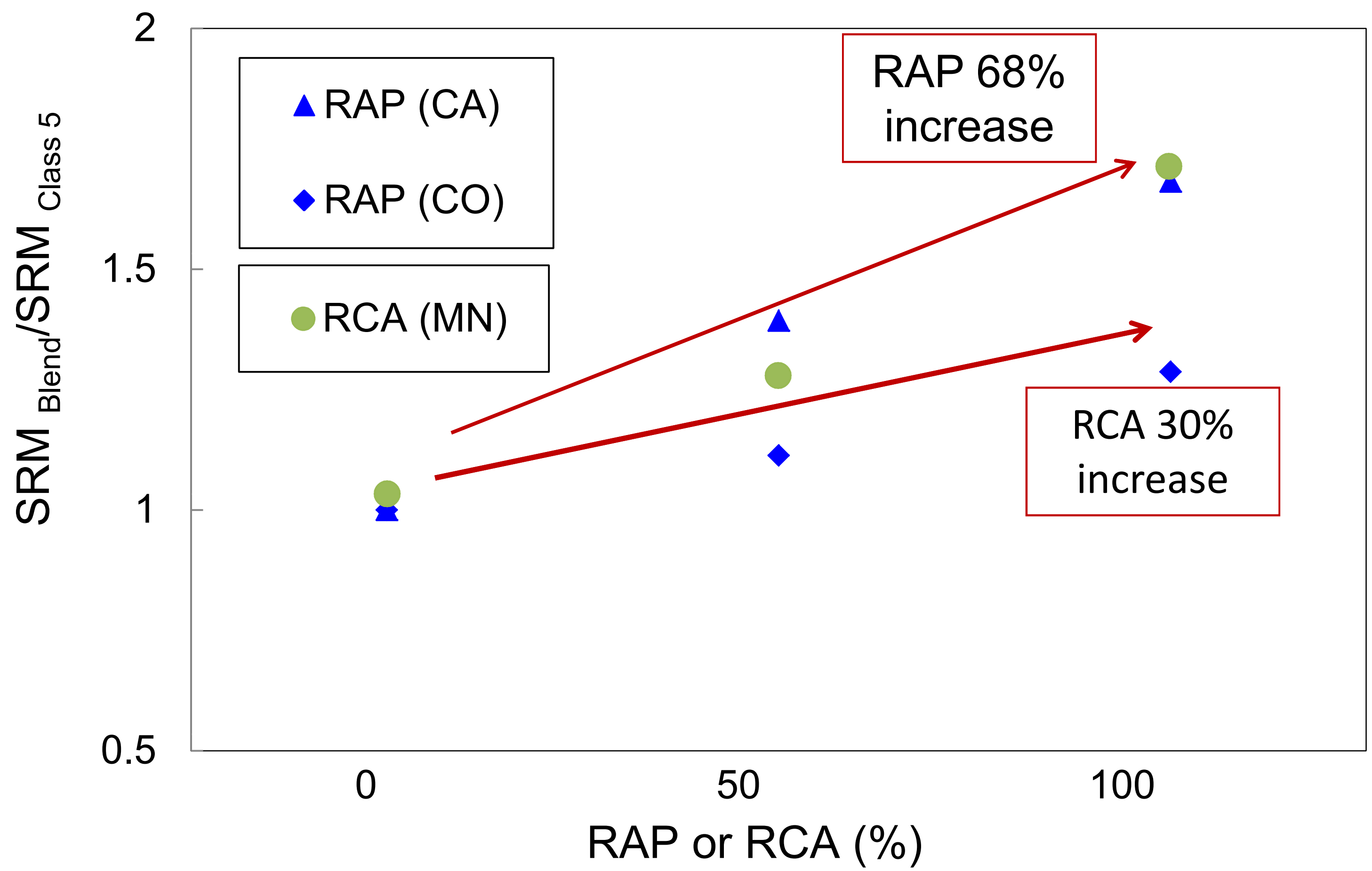


SRM vs



800
700
600
500
400
300
200
100
Internal SRM (MPa)
0
50
100
RAP or RCA (%)
RAP (CA)
RAP (CO)
RCA (MN)

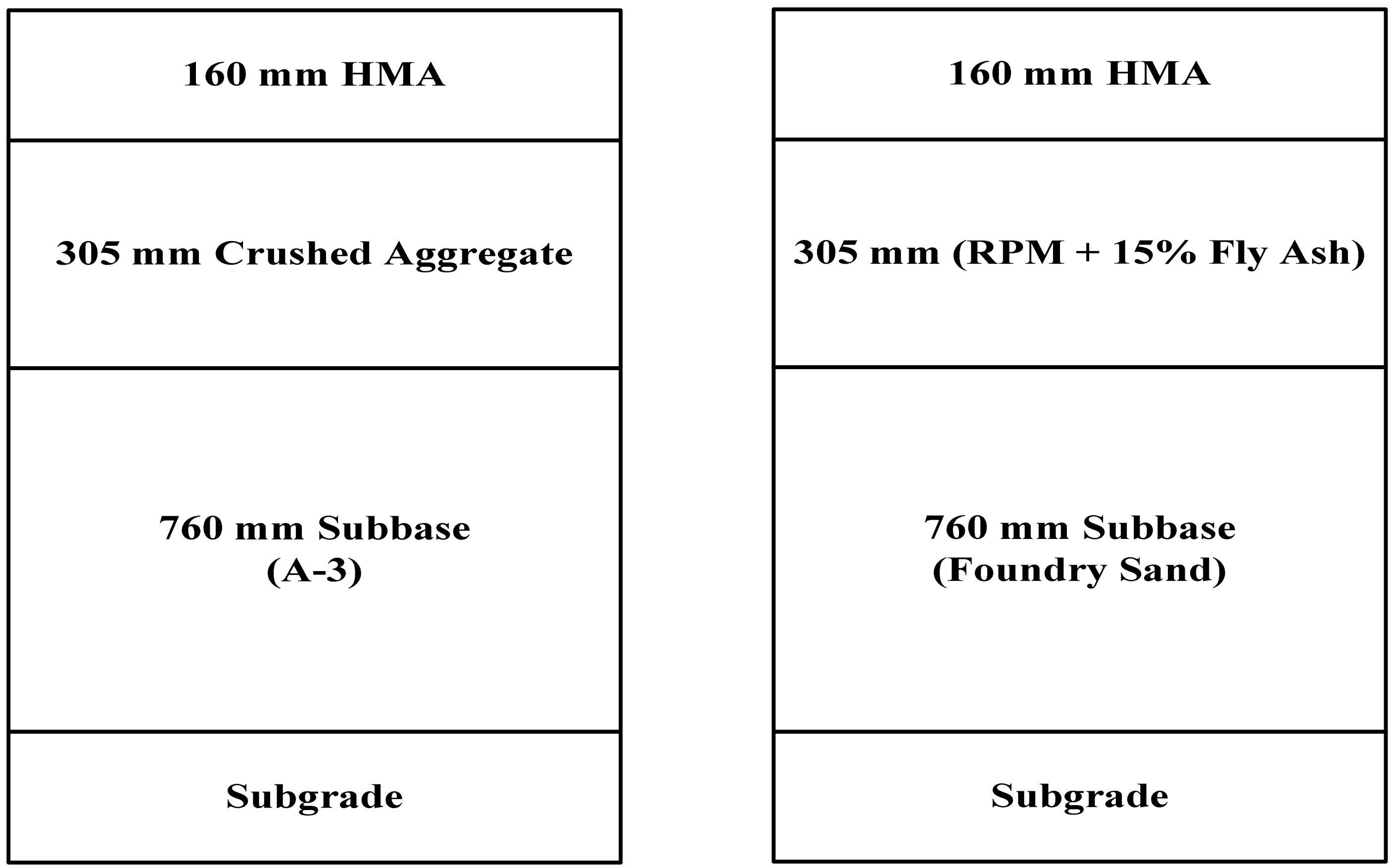
Results



RAP (CA)
RAP (CO)
RCA (MN)
RAP 68% increase
RCA 30% increase
2
1.5
1
0.5
0
50
100
RAP or RCA (%)
SRM Blend/SRM Class 5

Quantitative Assessment of Environmental and Economic Benefits of Using Recycled Construction Materials in Highway Construction

Schematic of Two Pavement Designs:
Reference-Conventional Materials vs. Alternative-Recycled Materials



Reference
(Conventional materials)

Alternative
(Recycled materials)

Life Cycle Analysis (LCA)

Environ-mental Metric	Conventional Materials			Recycled Materials			Differ-ence
	Material Productio n	Transpor-tation	Con-struction	Material Production	Transpor-tation	Con-structio n	
CO_2 (Mg)	3630	323	111	3028	163	54	-20%
Energy (GJ)	66,680	4318	1476	58,023	2187	723	-16%
RCRA Hazardous Waste (Mg)	629	31	9	611	16	4	-6%
Water (L)	17,185	735	144	15,637	372	70	-11%

Life Cycle Cost Analysis (LCCA)

Categories	Reference	Alternative	Saving
Agency Cost ($)	9,044,570	7,107,230	1,937,340 (21%)
User Cost ($)	10,570	8,380	2,190 (21%)
Total ($)	9,055,140	7,115,610	1,939,530 (21%)

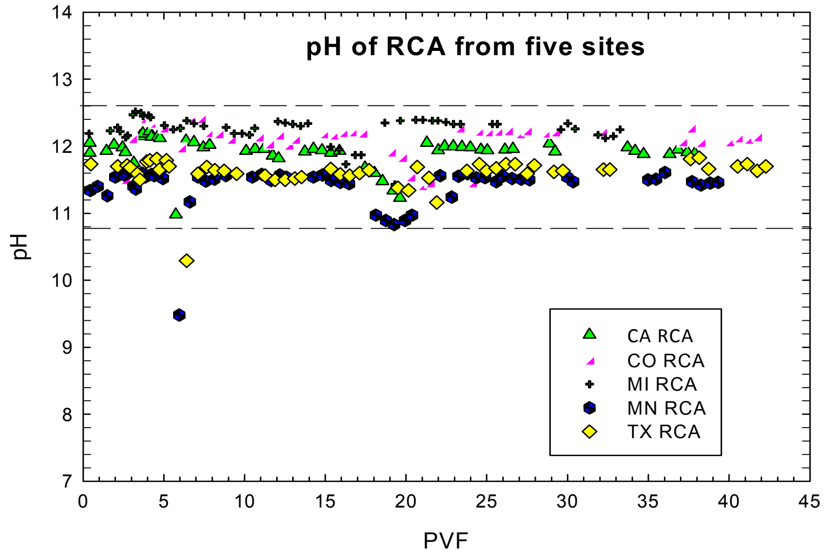
Conclusions Extrapolated to a Nationwide Scale

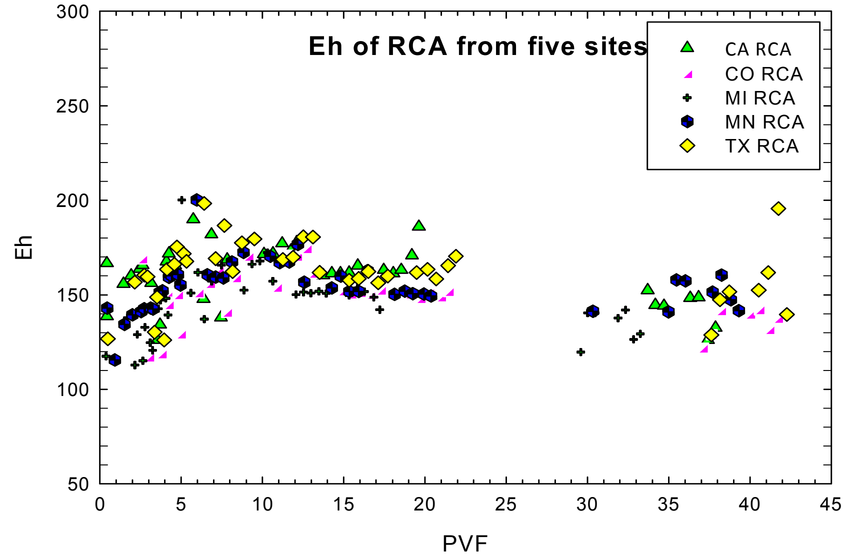
Point of Impact	Quantity	Equivalent to
Energy (PJ)	368	• Annual energy use for 3.67 million householders (EIA 2005 survey) • 68% of annual wind power generation in 2008 (EIA 2009)
Water (million L)	63	• 1.4 million persons daily water use for shower (43.9 L/capita)
CO_2e (million Mg)	26	• Equivalent to the removal of 5 million passenger cars per year from roadways
LCCA (billion $)	62	• Average annual salary for 1.5 million Americans ($39,500/yr)

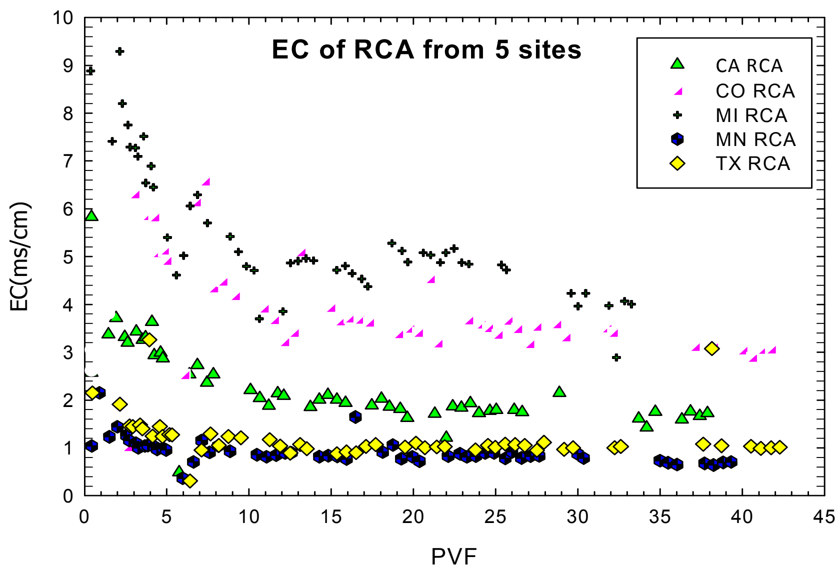
* Based on an assumption of 150,000 km annual road construction (Carpenter et al 2007)

Environmental Concerns

pH of RCA Column test(From 7-7-2010 to 9-16-2010)
The five kinds RCA are respectively: California RCA, Colorado RCA, Michigan RCA, Minnesota RCA and Texas RCA

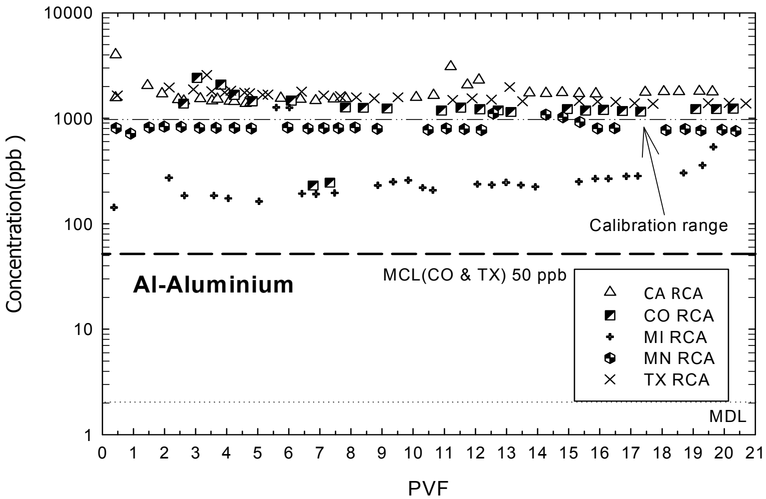




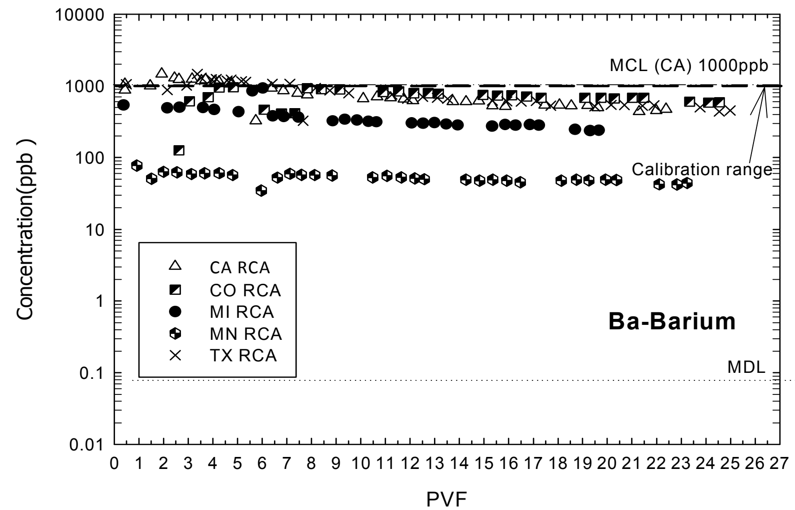


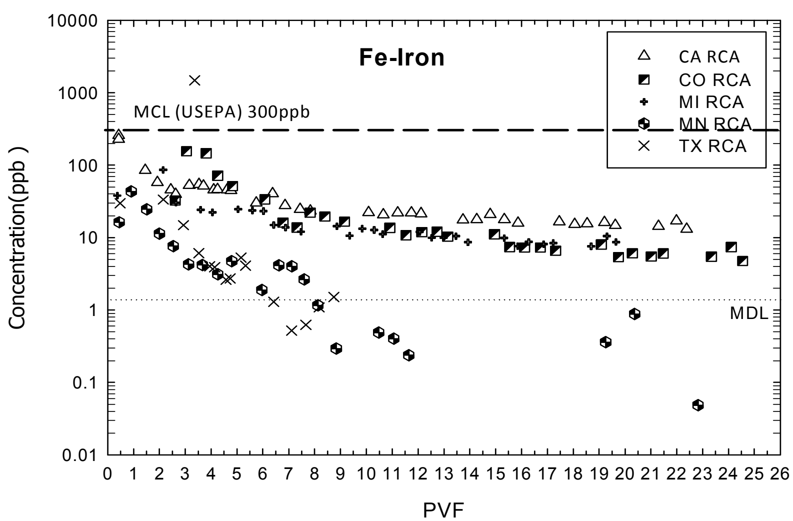
Take the 23 elements into consideration Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Ti, Tl, V, and Zn(From 7-7-2010 to 8-18-2010)

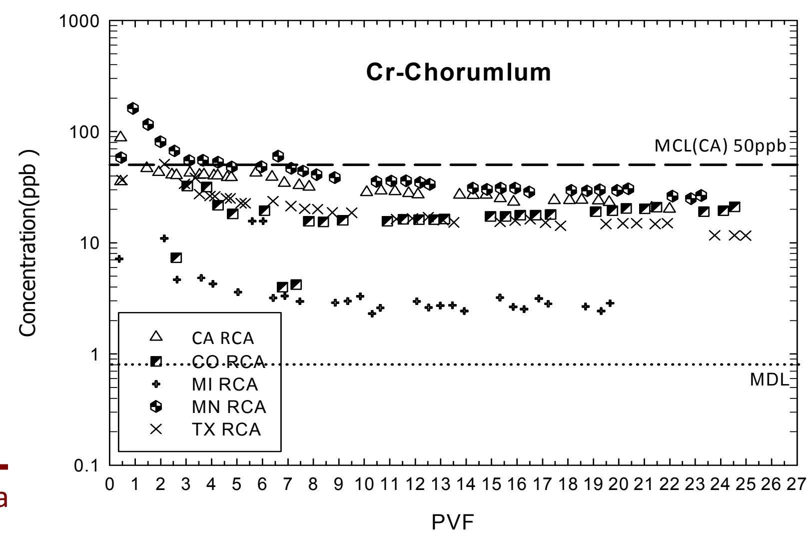
Elements MCL At lease once: Al, As*, Ba, Cr, Fe, Pb, Sb*, Se, Sr, Tl,

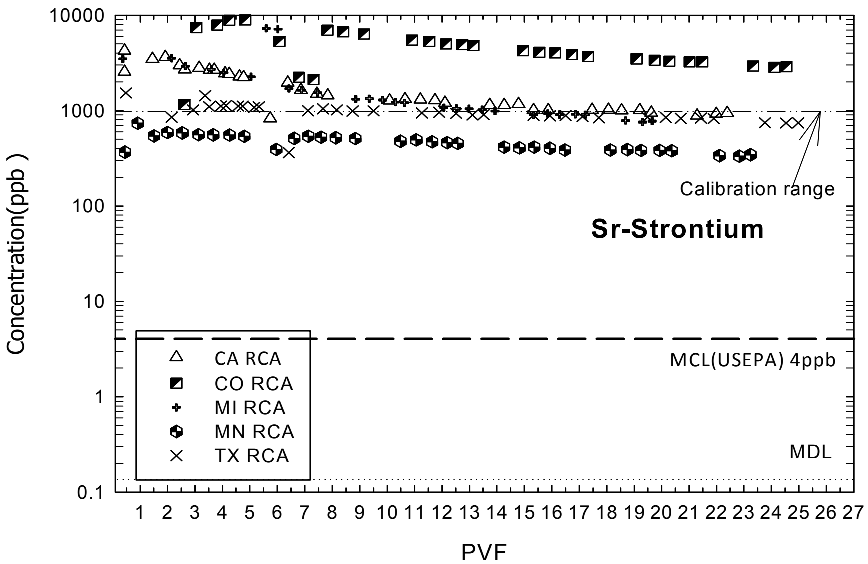


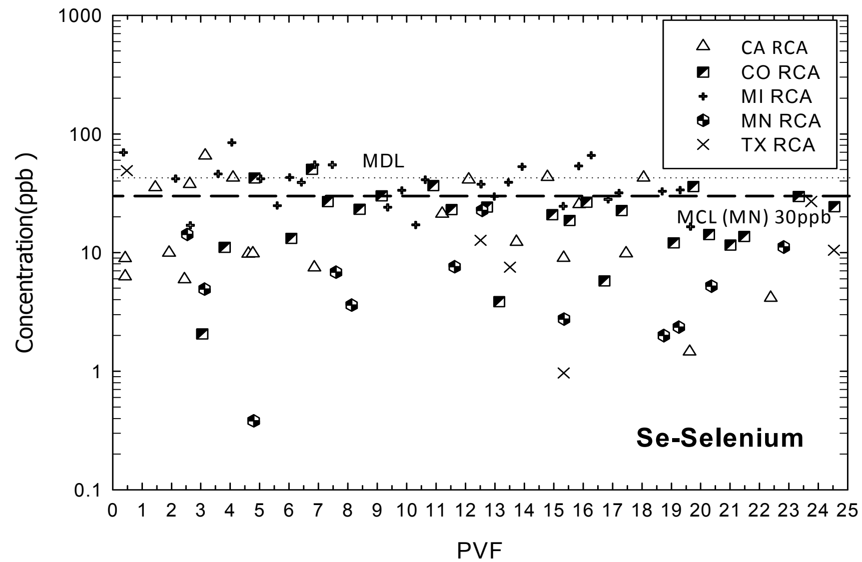
Note: Compared with the lowest MCL

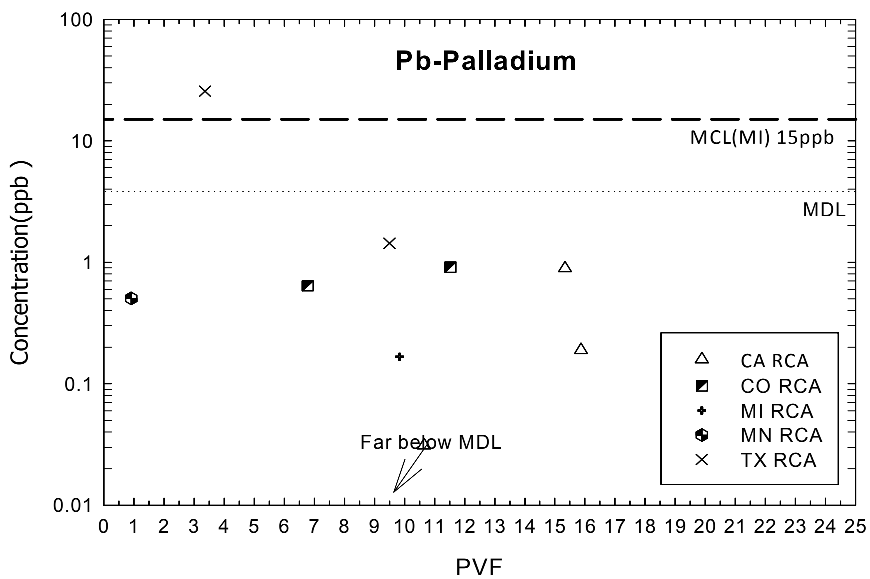












Note: ICP analysis slighty negative

Conclusions

- Freeze-thaw cycling reduces the SRM of RAP and natural aggregate.
  - The modulus loss of RAP over 20 cycles is comparable to that of natural aggregate (i.e., 28% vs 21%).
  - RAP with finer gradation experienced more modulus loss mostly in the first 5 cycles.
- RCA consistently displayed an unusual trend with freeze-thaw cycling first modulus decreasing up to 5 cycles followed with increasing up to 20 cycles

Questions?