ARC
Asphalt Research Consortium

Subtask E2b-1.a:

Impact of current extraction techniques on properties of extracted RAP aggregates

UNR and NCAT

HMA Recycling Expert Task Group
May 10, 2011
Irvine, California

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Develop a System to Evaluate the Properties of RAP
Objective

- Impact of current extraction techniques on properties of extracted RAP aggregates.

- Extract aggregates from simulated RAP mixes using:
  - Centrifuge (Trichloroethylene)
  - Reflux (Trichloroethylene)
  - Ignition oven

Develop a System to Evaluate the Properties of RAP

Aggregate Sources

- Nevada: Rhyolite (UNR)
- California: Granodiorite (UNR)
- Alabama: Hard Limestone (NCAT)
- Florida: Soft Limestone (NCAT)

Develop a System to Evaluate the Properties of RAP
Simulated RAP

- **SP mix design: intermediate gradation.**
- **Subject *loose* samples to STOA (4 hrs at 275°F) followed by LTOA (5 days at 185°F).**
- **Extract aggregates from aged loose specimens.**
- **Measure extracted aggregates physical properties.**

Develop a System to Evaluate the Properties of RAP

Extracted Binder Contents

Extraction Method	Aggregate Source	Rep	Extracted Binder Content (%)	True Binder Content (%)	Difference Between Extracted and True Binder Content	Allowable Difference Two-Sigma (d2s)	p-value (α=0.05)	95% CI[a]	Sig. level[b]
Centrifuge	Alabama	13	4.87	5.30	0.430	0.520	< 0.001	4.70–5.04	SL
	Florida	12	5.43	6.00	0.570*		< 0.001	5.29–5.57	SL
	Nevada	4	5.65	5.85	0.200		< 0.001	5.62–5.68	SL
	California	4	4.61	4.89	0.280		0.002	4.53–4.69	SL
Reflux	Alabama	15	4.98	5.30	0.320	0.520	< 0.001	4.85–5.11	SL
	Florida	12	5.62	6.00	0.380		< 0.001	5.51–5.73	SL
	Nevada	4	5.76	5.85	0.090		0.082	5.65–5.87	NS
	California	4	4.70	4.89	0.190		0.154	4.38–5.02	NS
Ignition Oven	Alabama	14	5.13	5.30	0.170	0.196	0.024	4.99–5.27	SL
	Florida	14	5.80	6.00	0.200*		0.001	5.70–5.90	SL
	Nevada	3	5.79	5.85	0.060		0.001	5.77–5.81	SL
	California	3	4.82	4.89	0.070		0.007	4.80–4.85	SL

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Measured Aggregate Properties

Property	Specification
Sieve Analysis	AASHTO T 27, T30
Coarse Aggregate Durability	AASHTO T 210
Fine Aggregate Durability	AASHTO T 210
Sand Equivalent	AASHTO T 176
LA Abrasion	AASHTO T 96
Specific Gravity and Absorption of Coarse Aggregate	AASHTO T 85
Specific Gravity and Absorption of Fine Aggregate	AASHTO T 84
Fine Aggregate Angularity	AASHTO T 304
Fractured Faces	ASTM D 5821
Percent of Loss in the Microdeval	ASTM D 7428
Soundness	AASHTO T 104
Aggregate Imaging System (AIMS)	--

Develop a System to Evaluate the Properties of RAP
Focus of the Presentation

- BSG of coarse aggregates & fine aggregates
- Consequences of extraction method on SP mix design.
- Effect of RAP aggregate SG on VMA

Develop a System to Evaluate the Properties of RAP

Coarse Aggregate – Bulk Dry Specific Gravities (Gsb)

Extraction Method	Aggregate Source	Average	Standard Deviation	Maximum Difference (Max – Min)	Difference Between Extracted and Virgin Aggregates	Allowable Difference Two-Sigma (d2s)	Paired Mean Comparisons
Coarse Aggregates							
None	Alabama	2.739	0.007	0.013	--	--	--
	Florida	2.419	0.009	0.017	--		--
	Nevada	2.584	0.008	0.018	--		--
	California	2.544	0.004	0.008	--		--
Centrifuge	Alabama	2.728	0.008	0.015	-0.011	0.025	NS
	Florida	2.430	0.005	0.009	0.011		SH
	Nevada	2.569	0.003	0.005	-0.015		SL
	California	2.521	0.007	0.014	-0.023		SL
Reflux	Alabama	2.725	0.002	0.003	-0.014	0.025	NS
	Florida	2.429	0.006	0.010	0.010		SH
	Nevada	2.581	0.004	0.008	-0.003		NS
	California	2.561	0.003	0.006	0.017		SH
Ignition Oven	Alabama	2.683	0.004	0.007	-0.056*	0.025	SL
	Florida	2.400	0.007	0.013	-0.019		SL
	Nevada	2.564	0.007	0.015	-0.020		SL
	California	2.538	0.006	0.012	-0.006		NS

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Fine Aggregate – Bulk Dry Specific Gravities (Gsb)

Extraction Method	Aggregate Source	Average	Standard Deviation	Maximum Difference (Max – Min)	Difference Between Extracted and Virgin Aggregates	Allowable Difference Two-Sigma (d2s)	Paired Mean Comparisons
Fine Aggregates							
None	Alabama	2.661	0.004	0.007	--	--	--
	Florida	2.585	0.010	0.010	--		--
	Nevada	2.491	0.010	0.019	--		--
	California	2.541	0.009	0.017	--		--
Centrifuge	Alabama	2.711	0.015	0.029	0.050*	0.032	SH
	Florida	2.583	< 0.001	0.010	-0.002		NS
	Nevada	2.486	0.016	0.031	-0.005		NS
	California	2.577	0.010	0.021	0.036*		SH
Reflux	Alabama	2.718	0.010	0.019	0.057*	0.032	SH
	Florida	2.622	0.010	0.020	0.037*		SH
	Nevada	2.522	0.013	0.025	0.031		NS
	California	2.576	0.010	0.021	0.035*		SH
Ignition Oven	Alabama	2.690	0.004	0.007	0.029	0.032	SH
	Florida	2.521	0.010	0.020	-0.064*		SL
	Nevada	2.512	0.017	0.032	0.021		NS
	California	2.583	0.008	0.015	0.042*		SH

Develop a System to Evaluate the Properties of RAP

Summary of Paired Mean Comparisons Results for Various Aggregate Properties

Aggregate Properties	Centrifuge			Reflux			Ignition		
	SL	NS	SH	SL	NS	SH	SL	NS	SH
Sieve analysis									
- 1/2 inch sieve	--	4	--	--	4	--	--	4	--
- No. 4 sieve	--	4	--	1	2	1	--	3	1
- No. 8 sieve	1	2	1	2	1	1	1	2	1
- No. 50 sieve	1	1	2	1	2	1	--	2	2
- No. 200 sieve	1	2	1	1	2	1	2	--	2
Coarse aggregate specific gravities									
- Bulk dry specific gravity	2	1	1	--	2	2	3	1	--
- Saturated surface dry specific gravity	1	3	--	1	3	--	1	3	--
- Apparent specific gravity	1	3	--	1	3	--	1	3	--
Fine aggregate specific gravities									
- Bulk dry specific gravity	--	2	2	--	1	3	1	1	2
- Saturated surface dry specific gravity	1	2	1	--	2	2	1	--	3
- Apparent specific gravity	1	3	--	1	3	--	--	3	1
Coarse aggregate absorption	1	3	--	3	1	--	--	1	3
Fine aggregate absorption	3	1	--	4	--	--	2	1	1
Coarse aggregate durability index	--	2	2	1	2	1	1	-	3
Sand equivalent	--	2	2	--	2	2	--	2	2
LA abrasion mass loss	1	3	--	--	3	1	--	1	3
Uncompacted void content	3	--	1	3	--	1	3	--	1

Develop a System to Evaluate the Properties of RAP

Consequences of the Extraction Method on the SP Mix Design

Aggregate Property	Centrifuge	Reflux	Ignition Oven
Passing #4 sieve	Close estimate 100% of time.	Close estimate 50% of time and 25% of time over- or under-estimate. *May result in spec violation 50% of time.*	Close estimate 75% of time and 25% of time over-estimate. *May results in spec violation 25% of time.*
Passing #200 sieve	Close estimate 50% of time and 25% of time over- or under-estimate. *May result in spec violation 50% of time.*	Close estimate 50% of time and 25% of time over- or under-estimate. *May result in spec violation 50% of time.*	Over-estimate 50% of time and under-estimate 50% of time. *May result in spec violation 50% of time.*
Combined bulk specific gravity, dry	Over-estimate 50% of time and under-estimate 50% of time.	Over-estimate 100% of time.	Over-estimate 50% of time and under-estimate 50% of time.

Develop a System to Evaluate the Properties of RAP
Effect of RAP Aggregate SG on VMA

- **SG of the combined gradation of RAP and virgin aggregates is required for the volumetric calculations of a mix design.**

- **BSG of each aggregate stockpile, including RAP aggregate needs to be determined for the calculation of BSG of combined aggregates.**

Develop a System to Evaluate the Properties of RAP

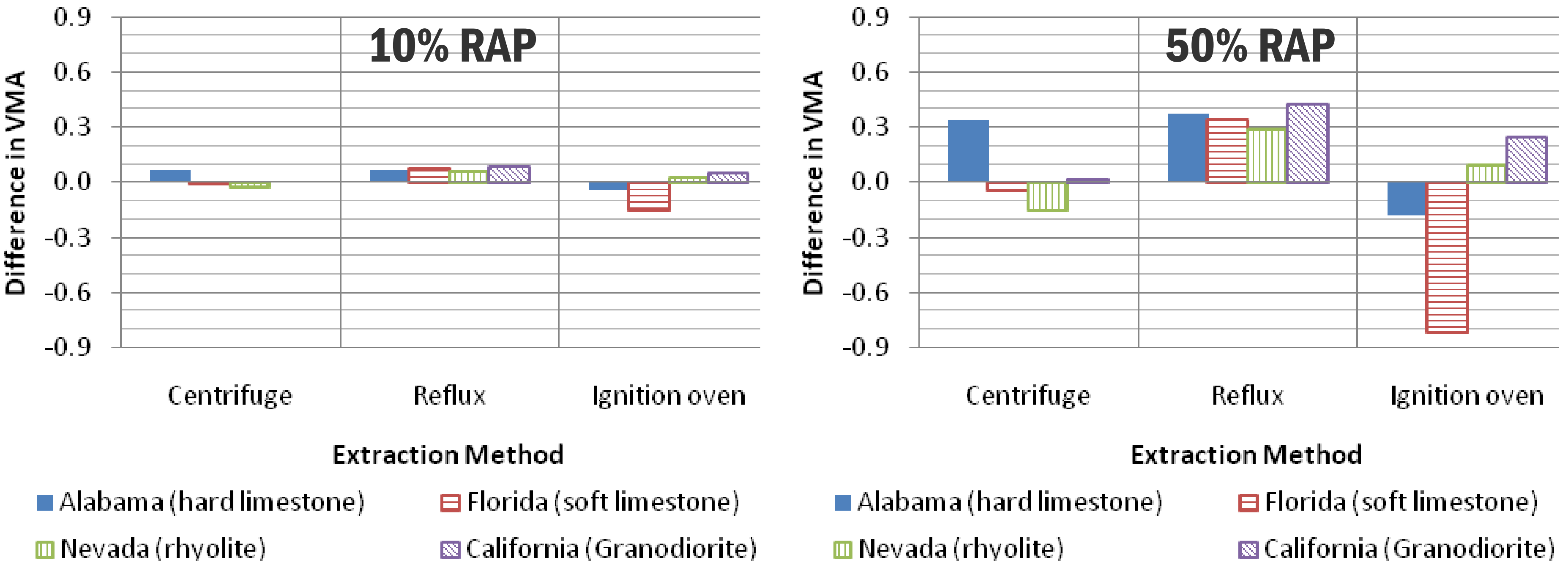
Effect of RAP Aggregate SG on VMA

RAP aggregate specific gravity (G_{sb})

- **Method A**
  - Measure extracted RAP aggregate SG
  - Measure % Fine Materials
- **Method B**
  - Assume P_{ba} for RAP aggregate
  - Measure RAP binder content & G_{mm}
- **Method C**
  - Use RAP aggregate G_{se} in lieu of G_{sb}
  - Measure RAP binder content & G_{mm}

Develop a System to Evaluate the Properties of RAP
Effect of RAP Aggregate SG on VMA

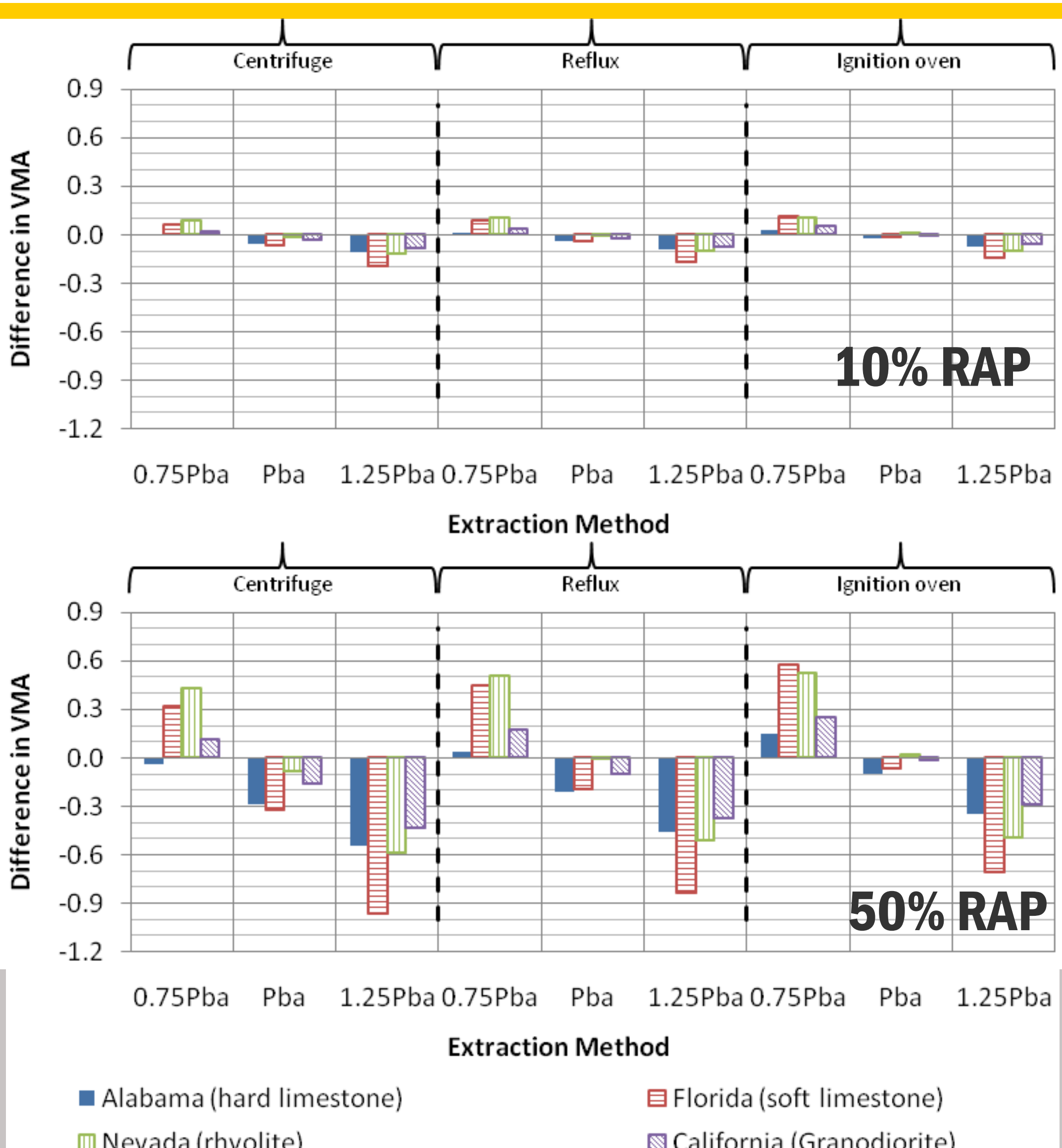
- *Method A:* **Difference in VMA**



Develop a System to Evaluate the Properties of RAP
Effect of RAP Aggregate SG on VMA

- ***Method B:***

  Difference in VMA



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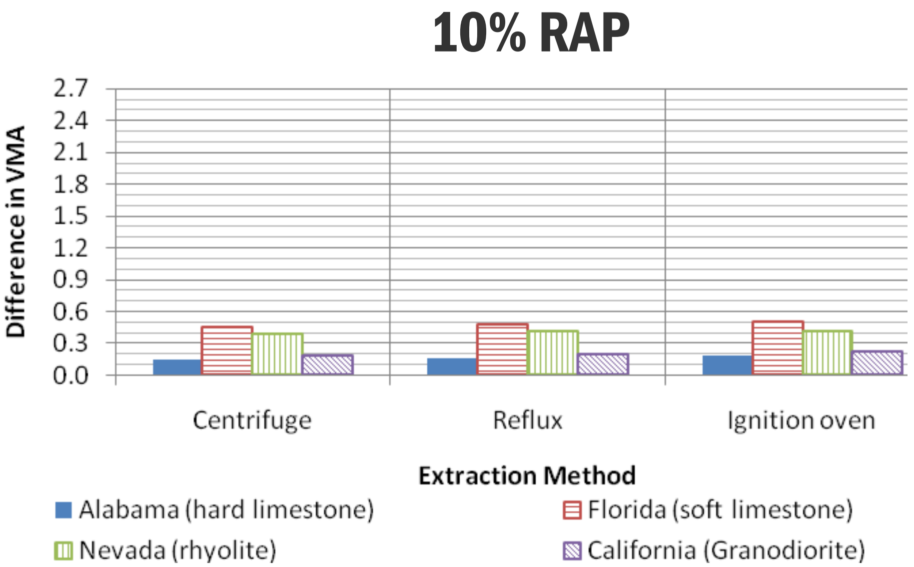
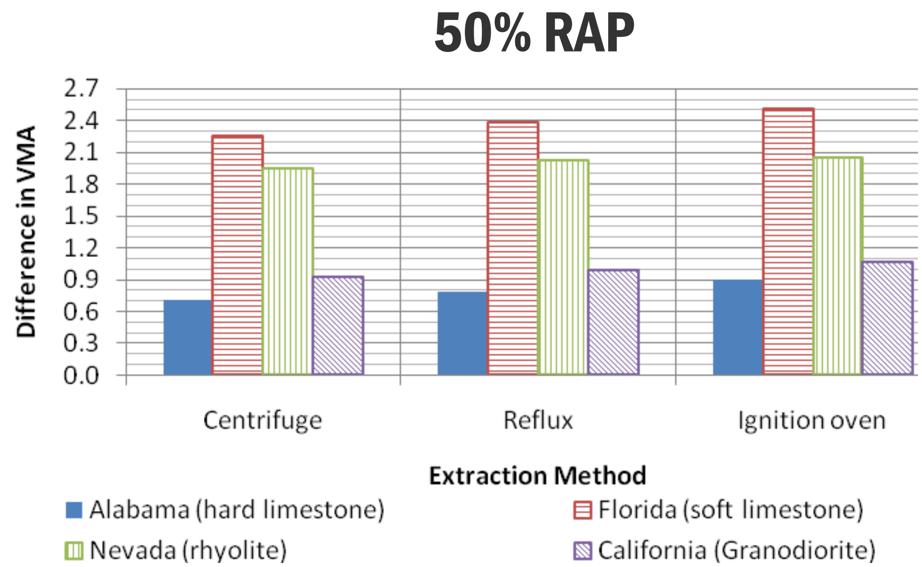
Develop a System to Evaluate the Properties of RAP
Effect of RAP Aggregate SG on VMA

- ***Method C:*** **Difference in VMA**





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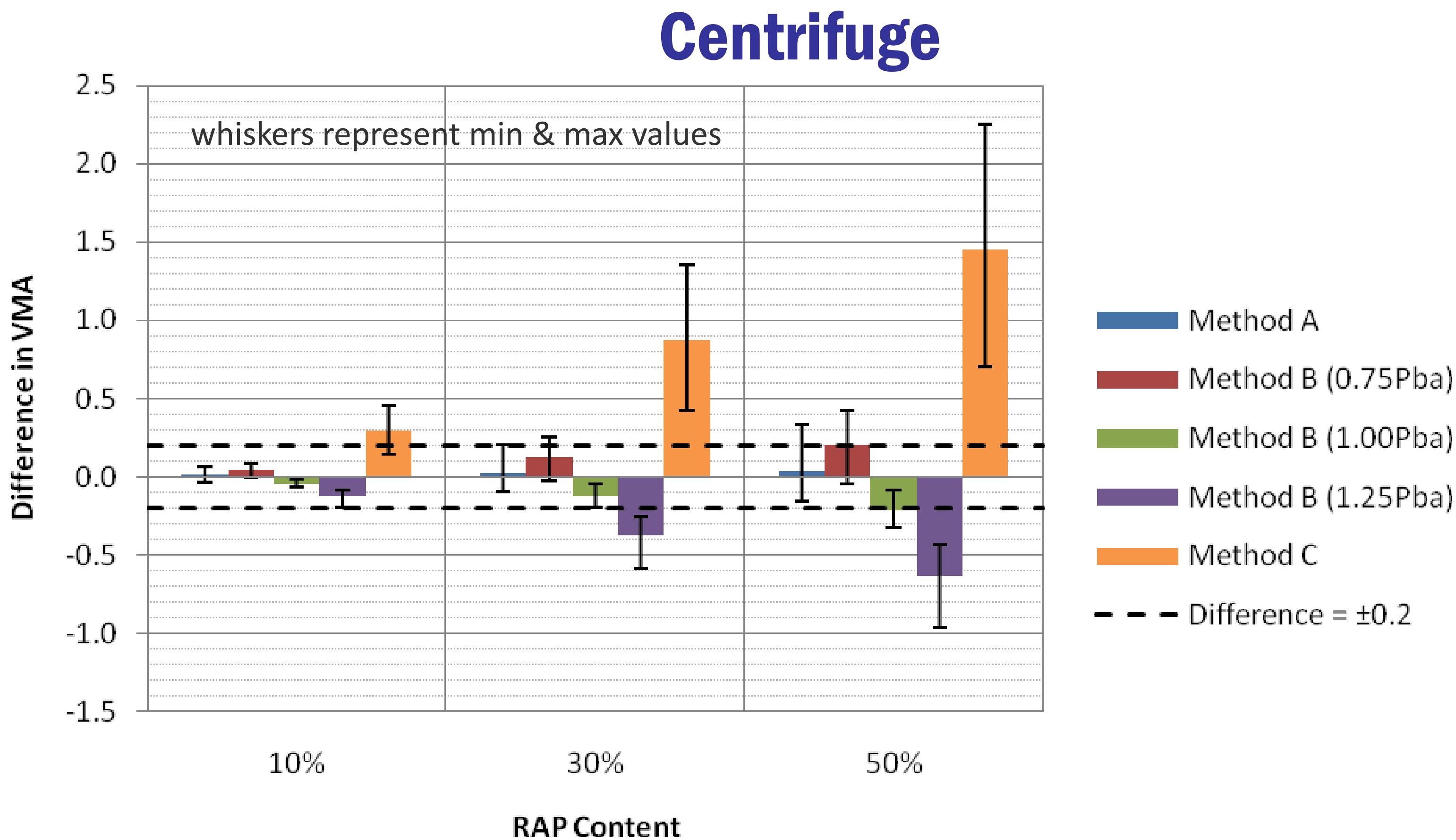
Effect of RAP Aggregate SG on VMA – Overall Summary



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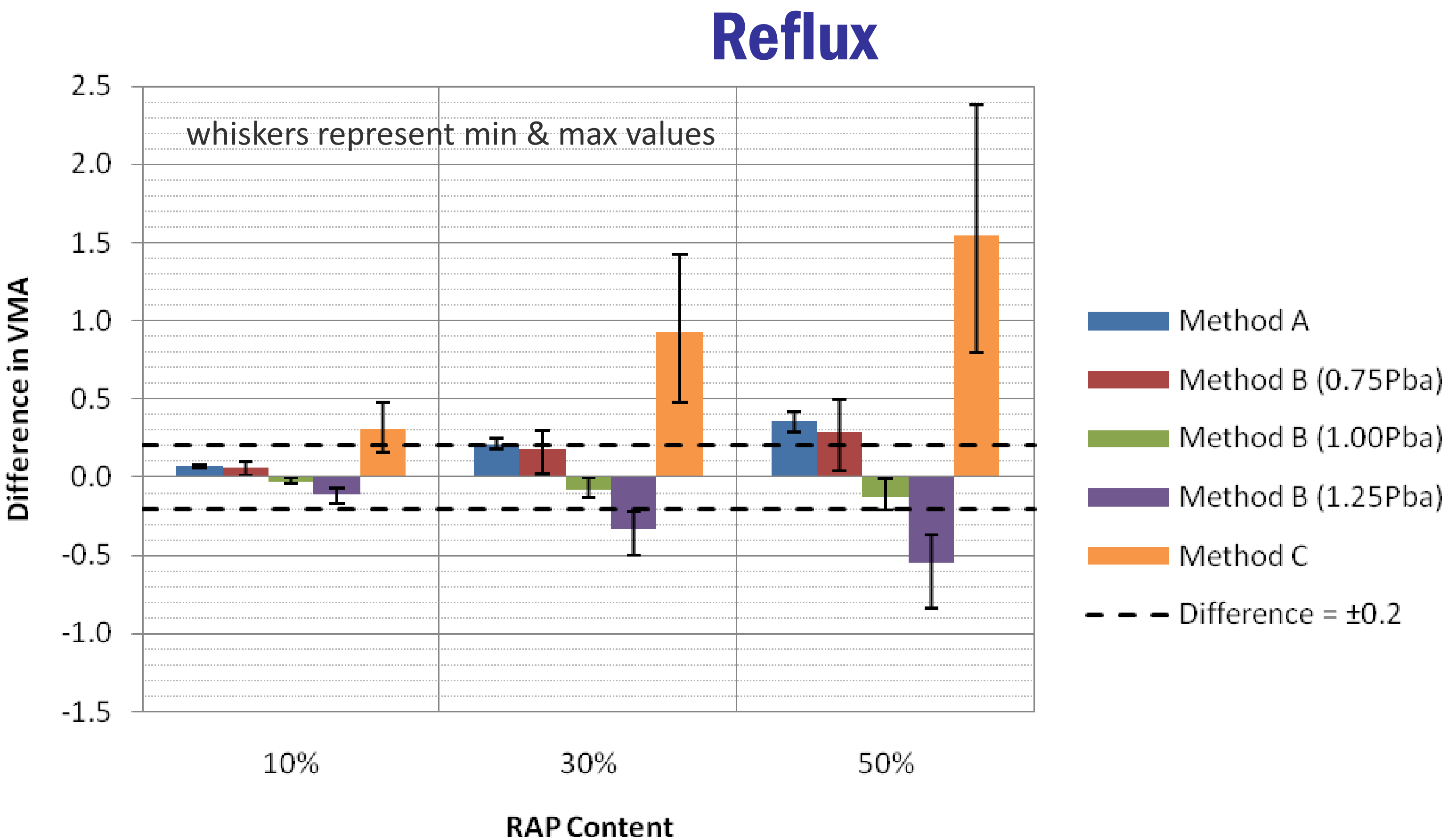
Effect of RAP Aggregate SG on VMA – Overall Summary



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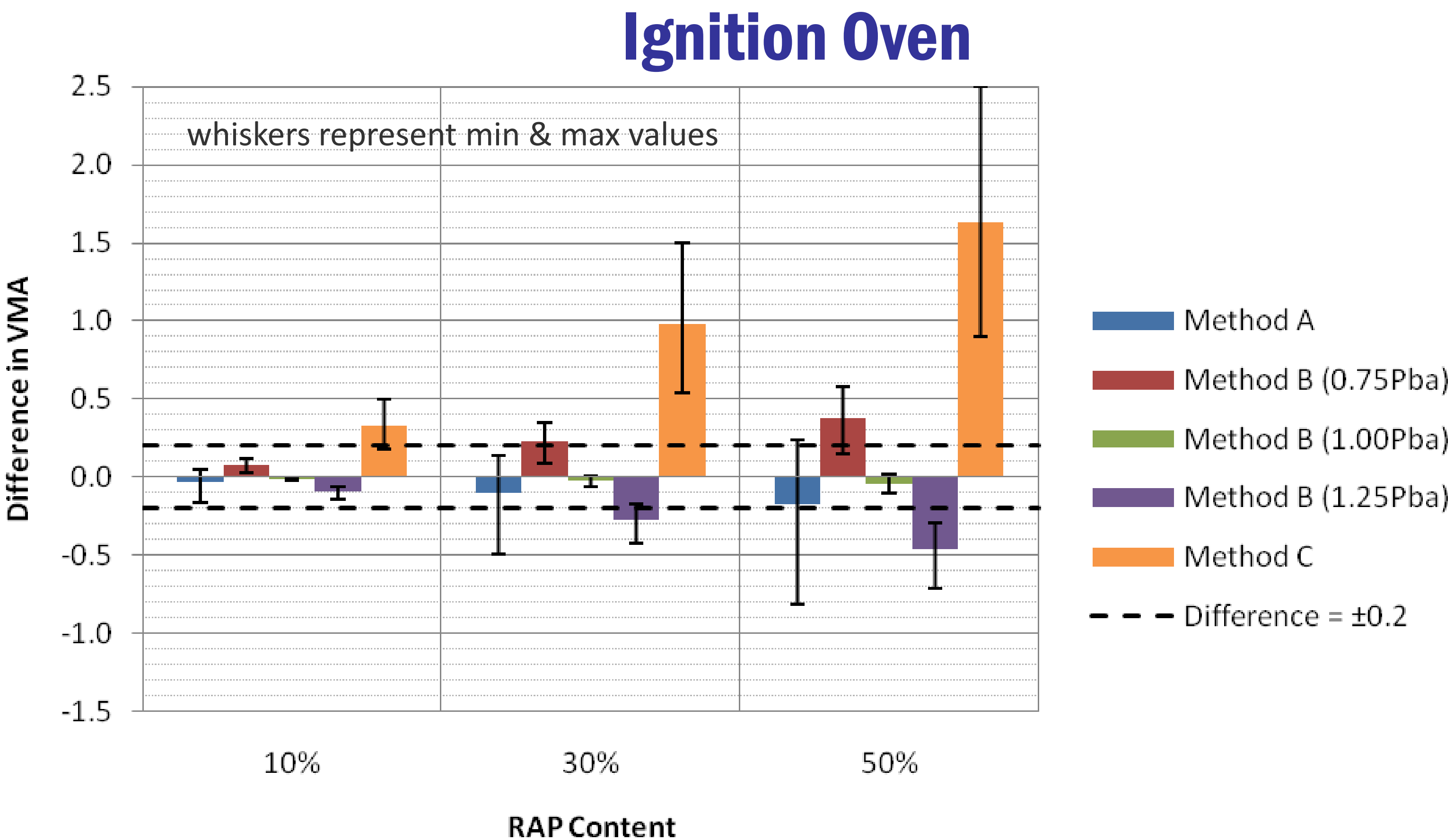
Effect of RAP Aggregate SG on VMA – Overall Summary



Summary/Recommendations

- RAP asphalt content:
  - Ignition method appears to give the most accurate results.
  - Solvent extraction methods do not appear to remove all of the aged binder from RAP
    - RAP asphalt contents using these methods tend to be lower than they actually are.

Summary/Recommendations

- RAP aggregate specific gravity:
  - For high RAP content mix designs, the best method for determining the RAP aggregate specific gravities is to use a solvent extraction method (centrifuge or reflux) to recover the aggregate and then test the coarse and fine parts of the recovered aggregate using AASHTO T85 and T84 respectively.

Summary/Recommendations

- RAP aggregate specific gravity (cont'd):
  - Ignition furnace may also be used to recover the RAP aggregate except for some aggregate types which undergo significant changes in specific gravity when subjected to the extreme temperatures used in the ignition method.
  - As RAP contents approach 50%, the net effect may be an error in the VMA determination of +/- 0.4%.

Summary/Recommendations

- RAP aggregate specific gravity (NCHRP Report 452) – *Method B*
  - Correct the G_{se} to an estimated G_{sb} using an assumed value for RAP asphalt absorption.
  - Correction is only reliable when asphalt absorption can be assumed with confidence.
  - Correction is very sensitive to the assumed asphalt absorption value and can lead to errors in VMA that are 0.5% or more.

Summary/Recommendations

- RAP aggregate specific gravity (NCHRP Report 452) – *Method C*
  - Although some agencies use the G_{se} for the RAP aggregate in the calculation of VMA, the authors strongly advise against this practice.

Recommended Practice

Methods for estimating RAP aggregate specific gravity	RAP Percentage			Expected Error in VMA
	Extraction Methods			
	Centrifuge	Reflux	Ignition Oven	
Method A[e]	≤ 25%	≤ 25%	≤ 10%	0.2%
	25% - 50%	25% - 50%	10% - 25%	0.4%
Method B [f,g]	≤ 10%	≤ 10%	≤ 15%	0.2%
	10% - 20%	10% - 20%	15% - 25%	0.4%

e using measured specific gravities of coarse and fine fractions of the extracted RAP aggregate along with the measured percent fine material (i.e. passing No. 4 sieve) in the RAP.
f assuming asphalt absorption along with measured theoretical maximum specific gravity and binder content for RAP.
g assumed asphalt absorption for the RAP aggregate within 25% of the true value.