Compatibility Characterization of Reclaimed Asphalt Pavement, Binder, and Recycling Agents in Asphalt Mixtures

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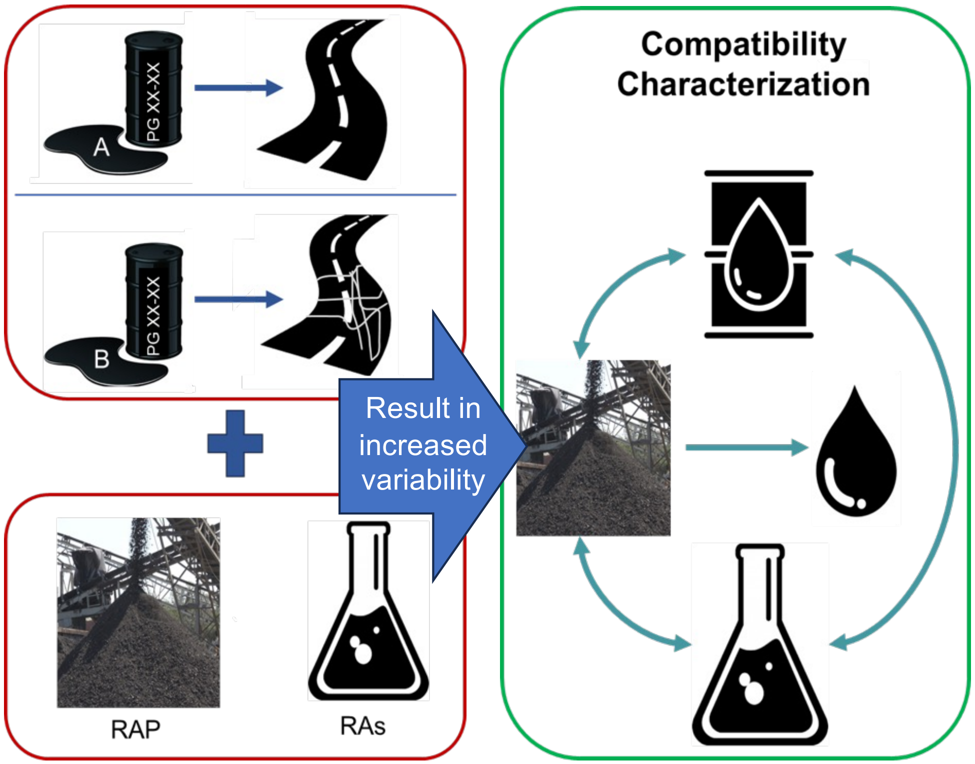
Goal and Study Objectives

Motivation



- **Objective:**
  - Develop a practical and implementable compatibility characterization system:
    - *Combination of various asphalt sources (virgin binders, recycled asphalt binders)*
    - *Combination of asphalt binders (virgin, recycled) with recycling agents*

Research Approach

Selection of core materials (3 binder sources, 3 RAP sources and 2 RAs)

Mix design and production of 21 mixture combinations using core materials: virgin, low RAP, high RAP, and high RAP treated with RAs

Binder extraction and recovery and PAV aging (1 and 2 cycles)

Laboratory characterization of binders and mixtures

Binder tests
Rheological characterization using DSR,
Thermal characterization using DSC

Mixture tests
Complex modulus (E*),
Illinois flexibility index (I-FIT), and
Disk-shaped compact tension (DCT)

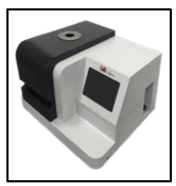
Binder Test Methods:
Dynamic Shear Rheometer, Differential Scanning Calorimetry, Thermo-gravimetric Analysis, and SARA Fractionation

Statistical analysis of the mixture and binder performance parameters

Recommendations for binder and mixture performance parameters for compatibility evaluation

Binder Evaluation and Material Matrix

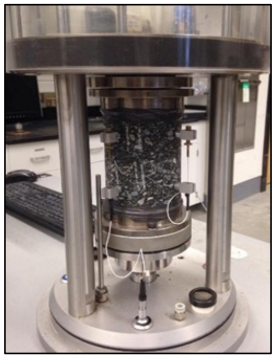
- **Binder Material**
  - 27 binder blends
    - 3 virgin binders
    - 3 LRAP and 7 HRAP blends
    - 14 RA-treated HRAP blends
- **Three Aging Level**
  - As-extracted
  - 1 × PAV
  - 2 × PAV
- **Test Methods**
  - Dynamic shear rheometer
  - Differential scanning calorimetry



Material Type	Material ID	Binder Grade (PG)	Source
RAP (graded as extracted)	**1**	**103.1-4.6**	Minnesota, US
	2	**103.8-5.8**	Alabama, US
	3	87.2-26	Texas, US
Binders	A	58-28	Minnesota, US
	B	**64-22**	Alabama, US
	C	**64-22**	Wisconsin, US
Recycling Agents	RA1	--	Bio-based
	RA2	--	Petroleum-based

Mixture Evaluation Methods

- **Mix Design**
  - 21 mixtures (3 virgin mixtures, 3 LRAP mixtures, 9 HRAP mixtures, 6 RA treated mixtures)
  - **Similar gradation and comparable volumetrics**
- **Mixture Tests**
  - Complex Modulus (AASHTO T 342)
  - Disk-Shaped Compact Tension (DCT) Test (ASTM D7313)
  - Illinois Flexibility Index Test (AASHTO T 393)



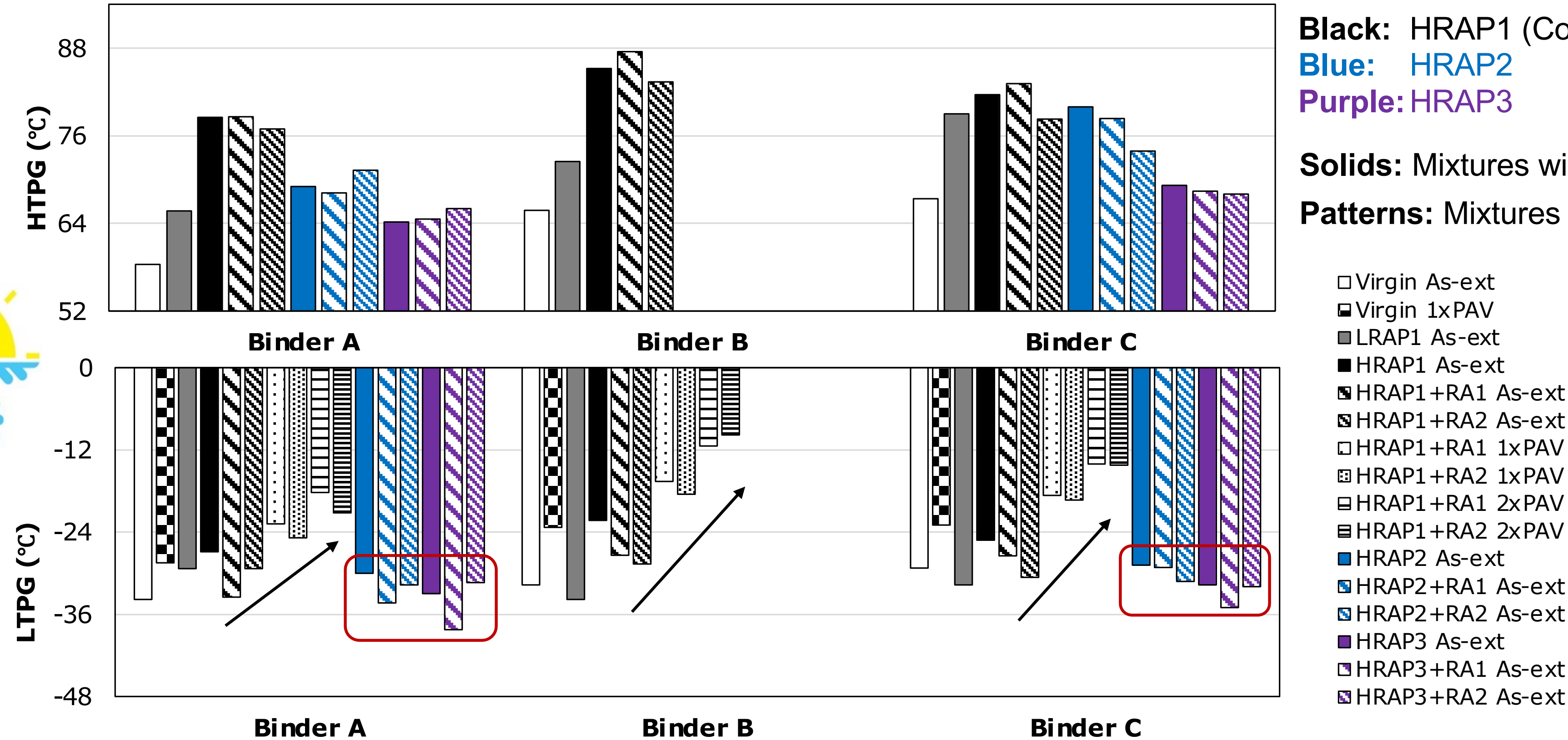
Complex Modulus

DCT

I-FIT

Part 1 : Binder Testing Results (Rheological and Thermal Analysis)

Continuous PG



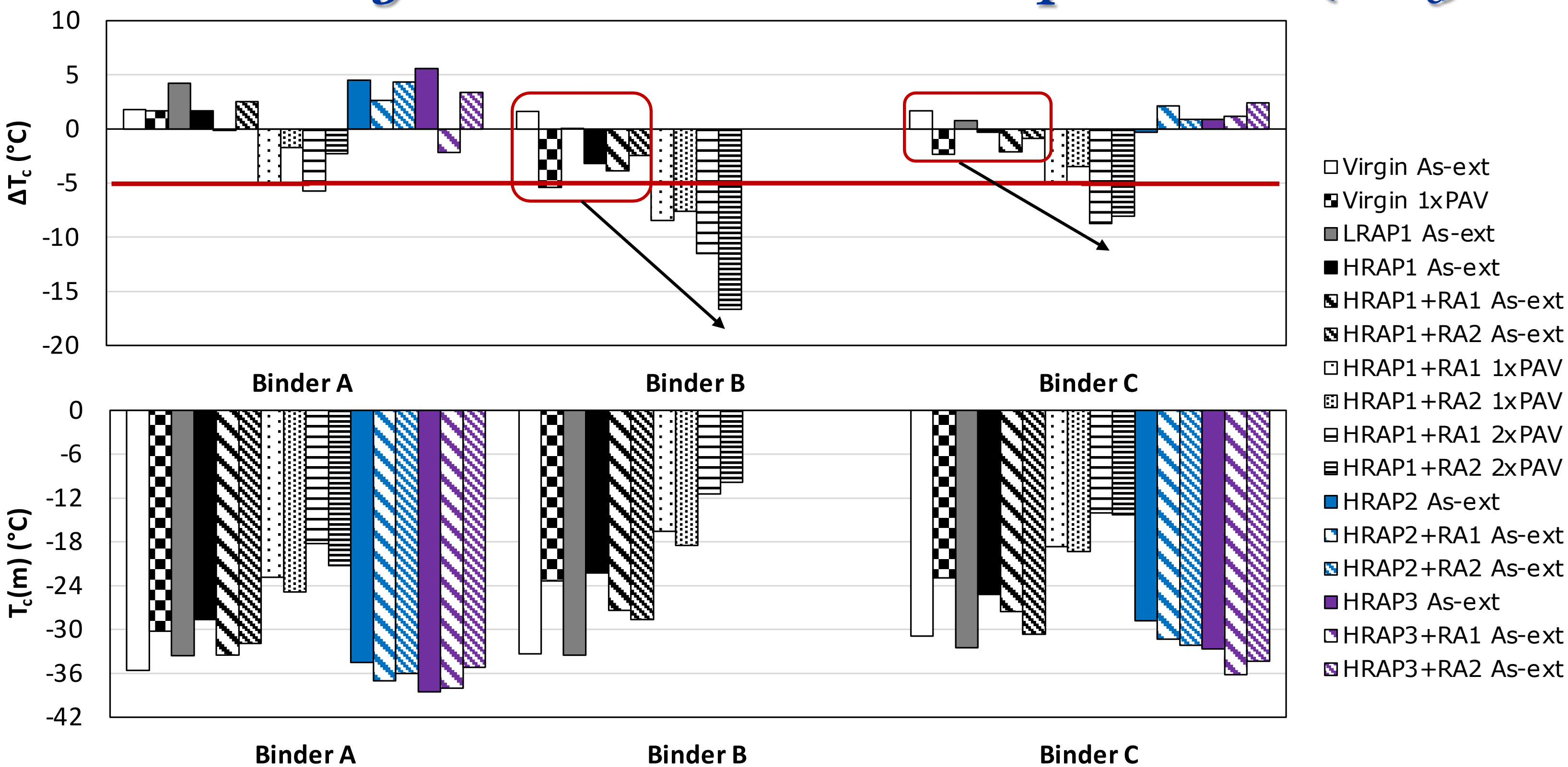
Black: HRAP1 (Control RAP)
Blue: HRAP2
Purple: HRAP3

Solids: Mixtures without RA

Patterns: Mixtures with RA

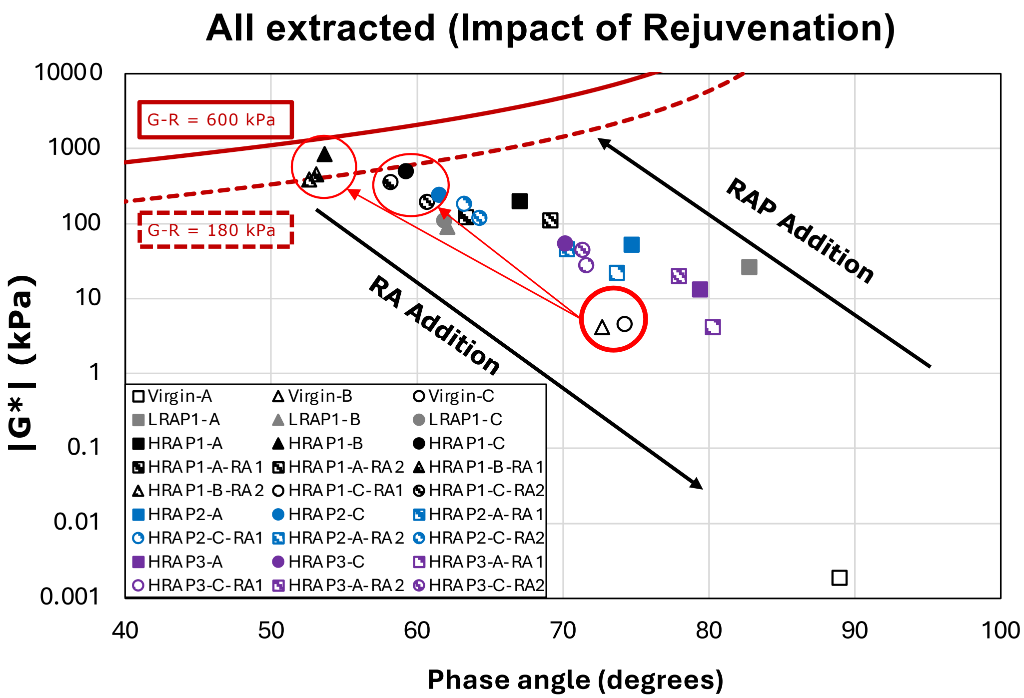
- Inclusion of RA results in small variation in HTPG
- RAP1 blends have the warmest LTPG with all binders among all RAP materials
- Binder B has higher aging susceptibility than Binder C

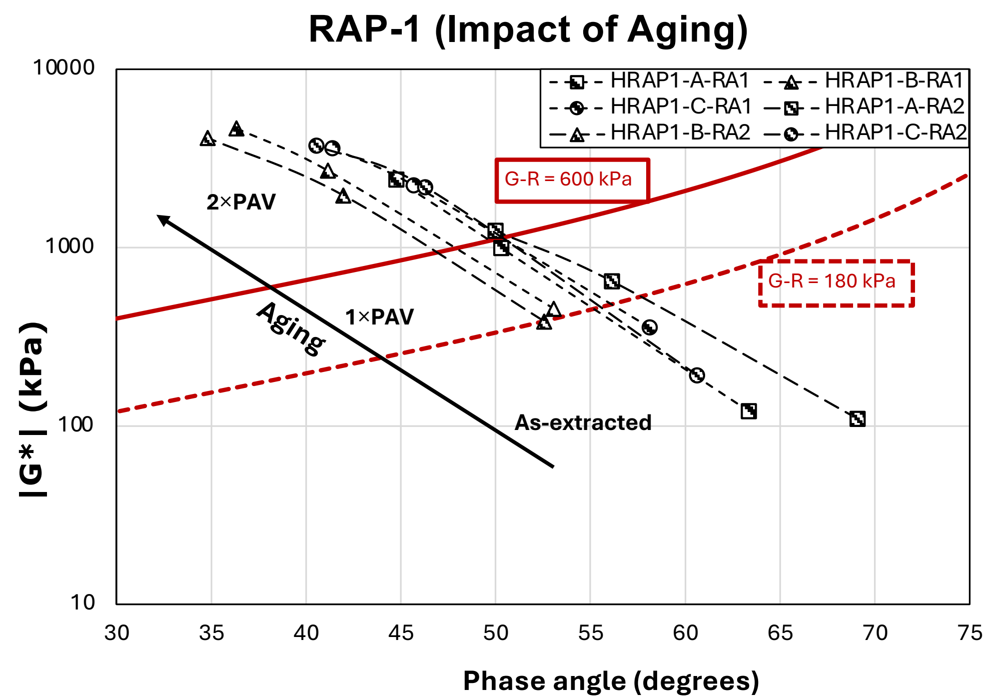
Change in Critical Low Temperature (ΔT_c)



- Binder B blends show poor ΔT_c values and the severe impact of aging (both B and C have similar PG)
- ΔT_c is a composite parameter and trends with ΔT_c should be evaluated in conjunction with $T_c(m)$

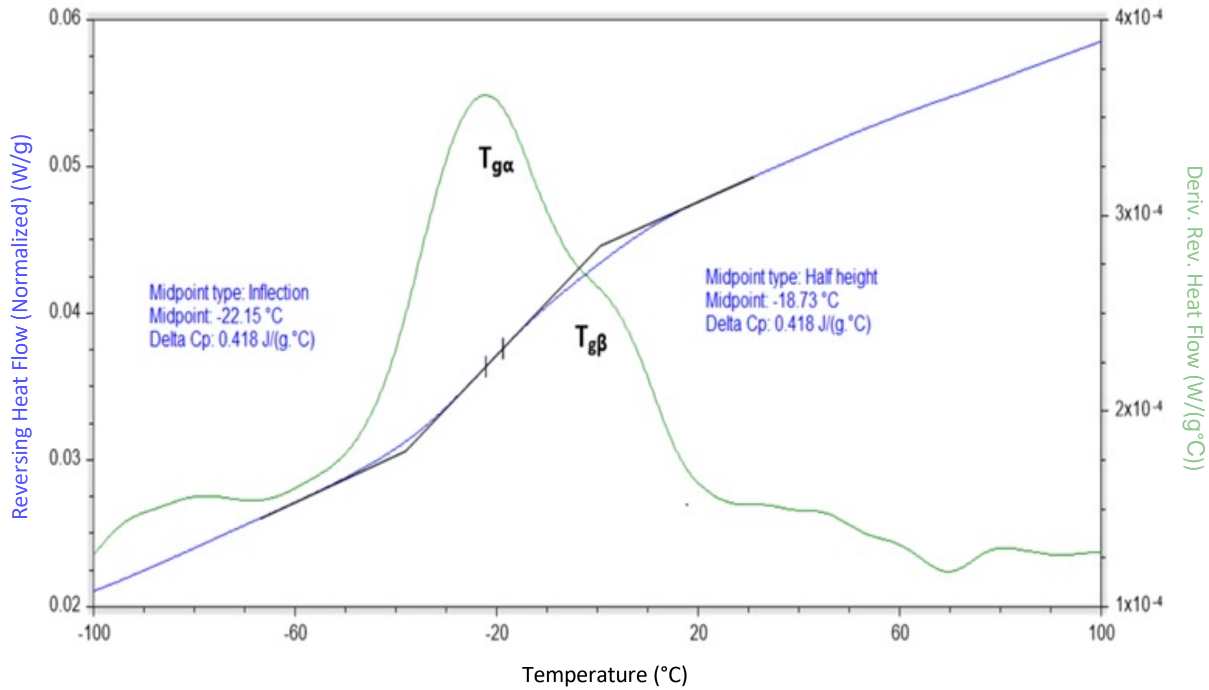
Black Space Analysis *(@15 °C and 0.005 rad/sec)*



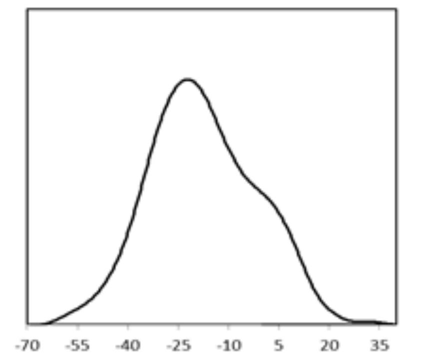


- Binder B blends exceed the warning limit and indicate potential incompatibility with both RAs
- Binder B blends have poor properties after all aging levels

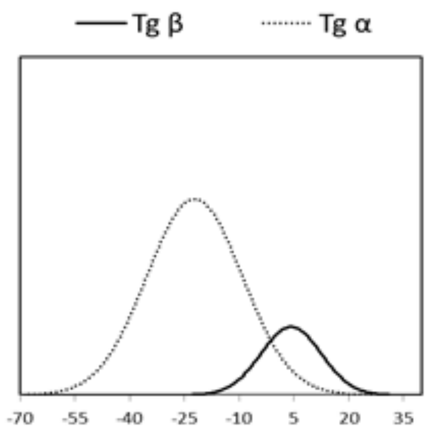
DSC Thermal Analysis: Parameters



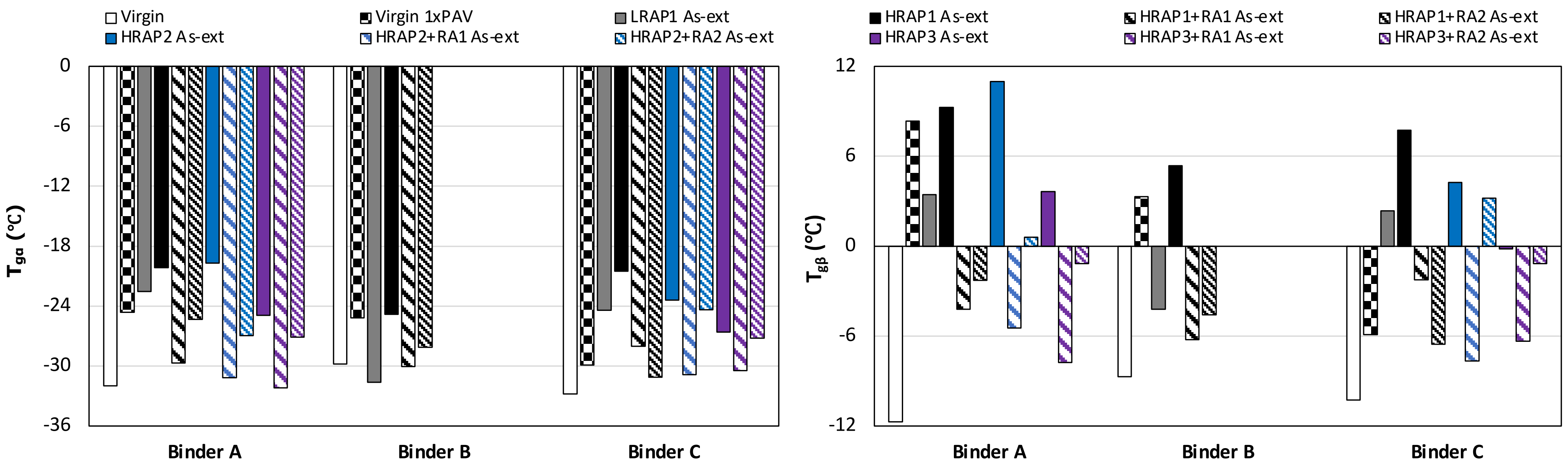
$$\phi_{\alpha,\beta} = \frac{\Delta H_{\alpha,\beta}}{\sum \Delta H}$$



Deconvolution



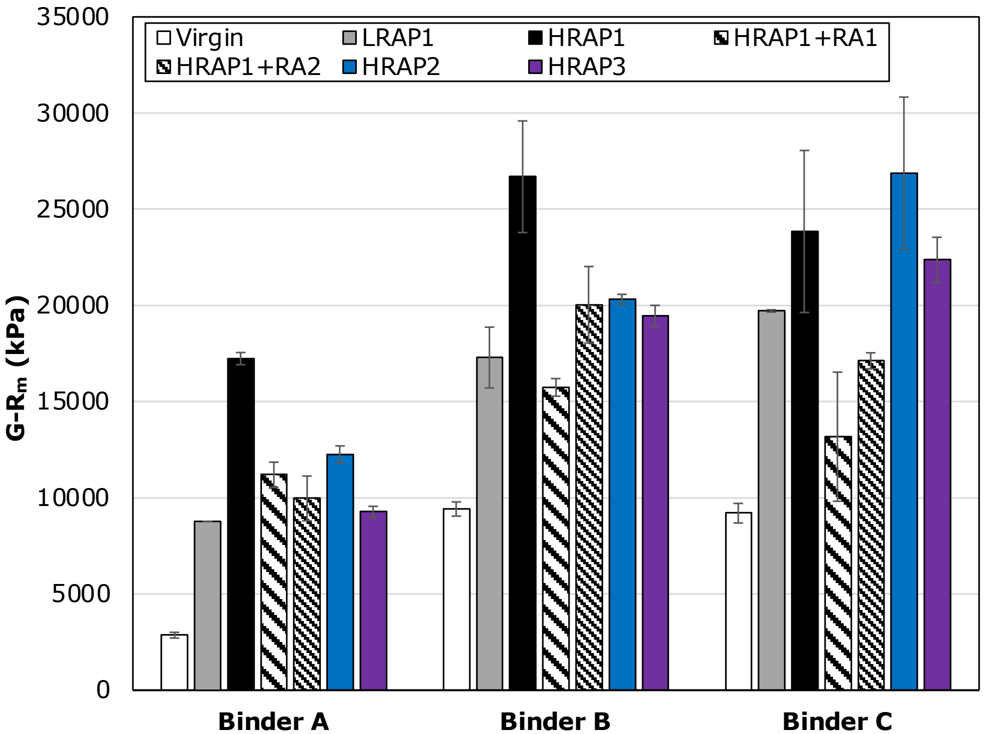
Thermal Analysis

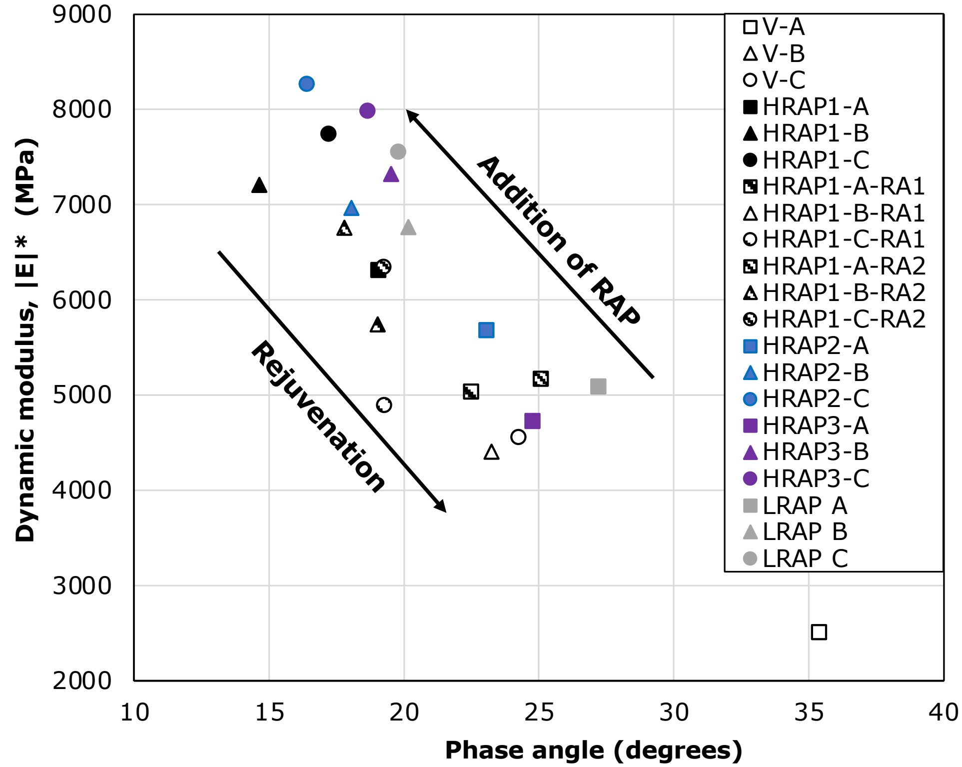


- The increase in RAP content shifted $T_{g\beta}$ to positive temperatures for all three binders
- Inclusion of both RAs reversed this trend, with RA1 generally resulting in a larger reversal indicating its higher effectiveness

Part 2 : Mixture Testing Results

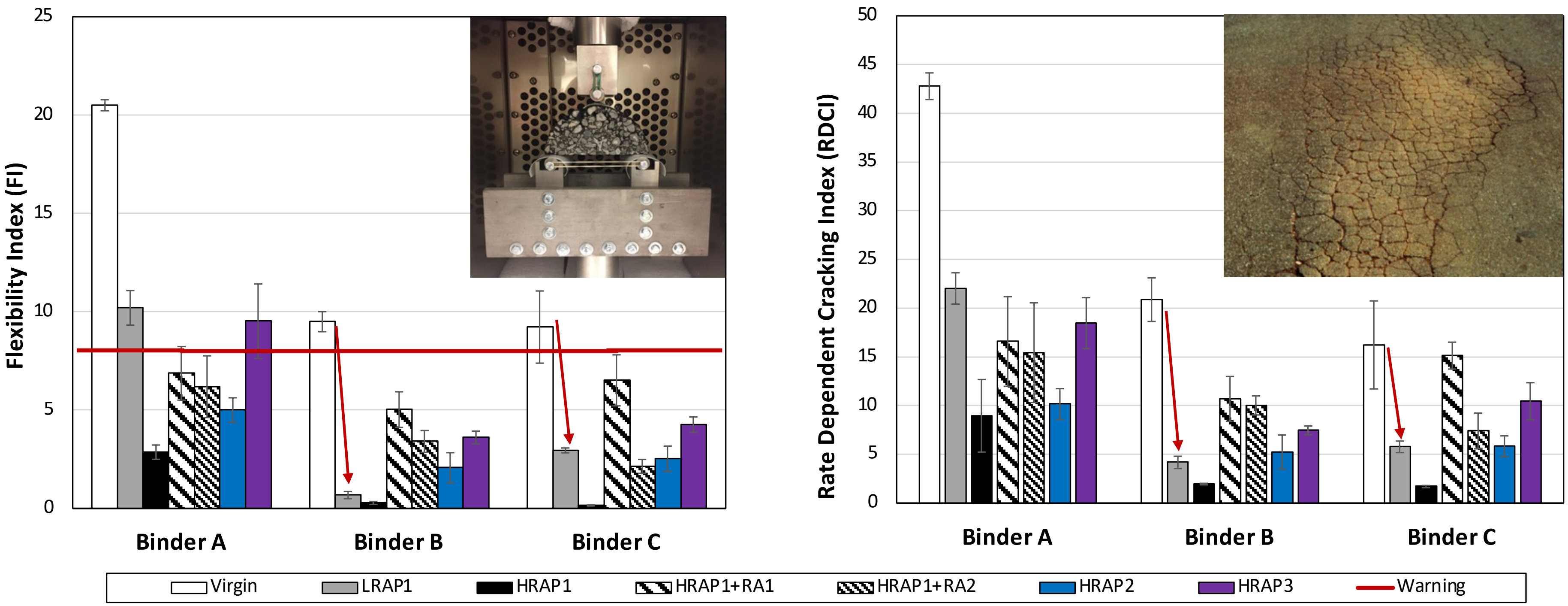
Complex Modulus Testing Results





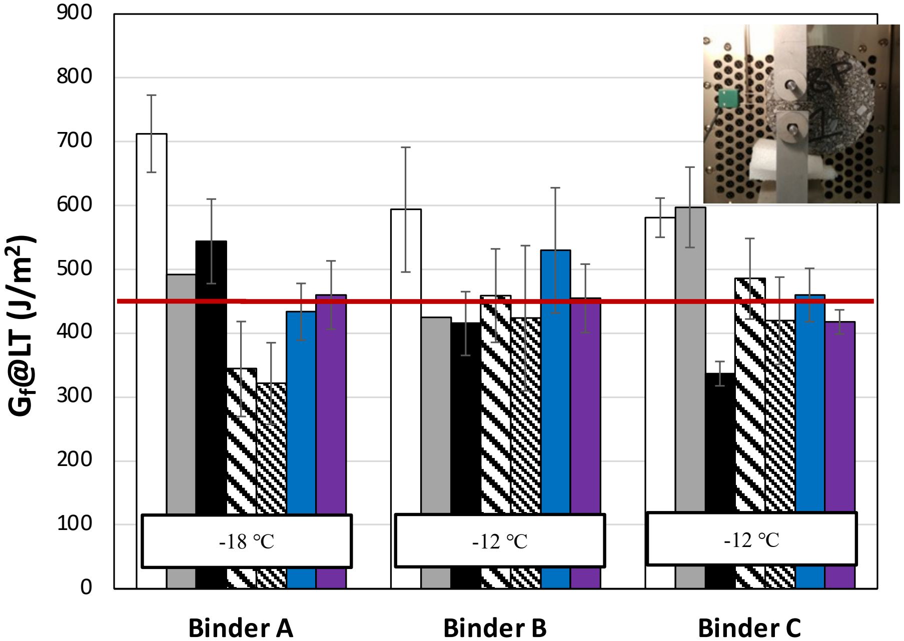
- Mixtures with both RA1 and RA2 show the **lower |E*| and higher δ**, however, RA1 generally resulting in a larger reduction indicating its higher effectiveness
- Mixtures with binder B shows lowest compatibility with control RAP and RA

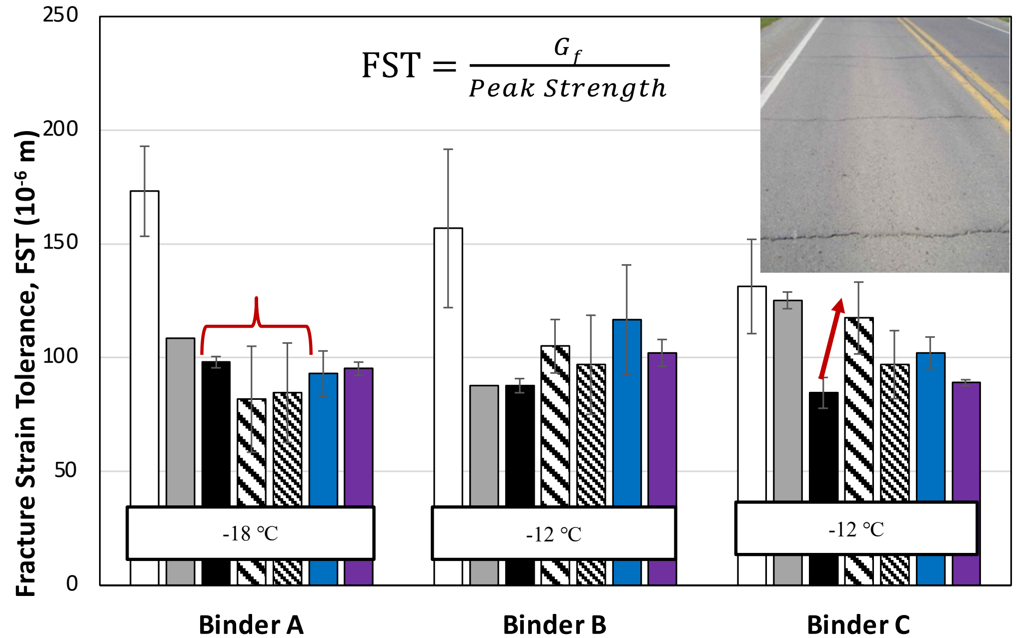
Intermediate Temperature Fracture : I-FIT Test



- Virgin B and C quite similar but the inclusion of RAP shows the difference
- RAP1 still more incompatible with all binders
- RAs improve the fracture performance properties at intermediate temperature, but RA1 showing better or similar performance to RA2

Low-Temperature Fracture: DCT Test





☐ Virgin ☐ LRAP1 ■ HRAP1 ▨ HRAP1+RA1 ▨ HRAP1+RA2 ■ HRAP2 ■ HRAP3

- FST shows that low temperature performance of binder A is not improved by RAs' presence
- RA1 significantly improve low temperature performance of RAP1 mixture with Binder C
- Intermediate temperature performance changes do not translate in exactly same manner to low temperature performance impacts

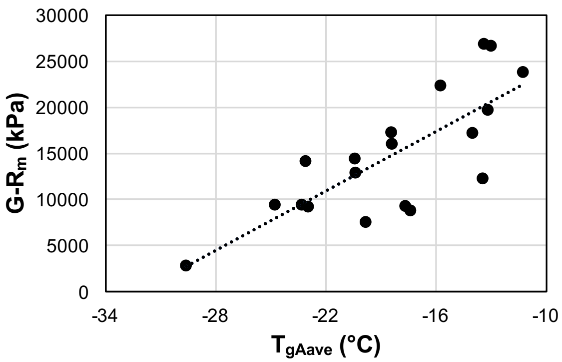
Part 3 : Statistical Analysis

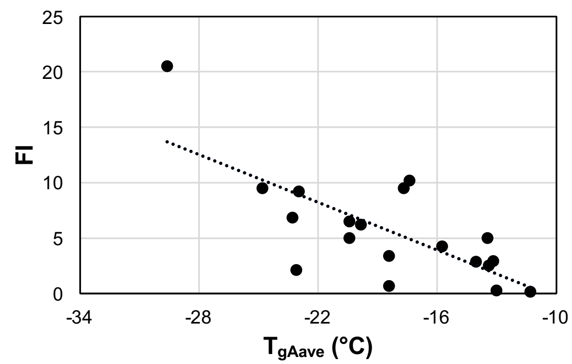
Statistical Analyses: Example

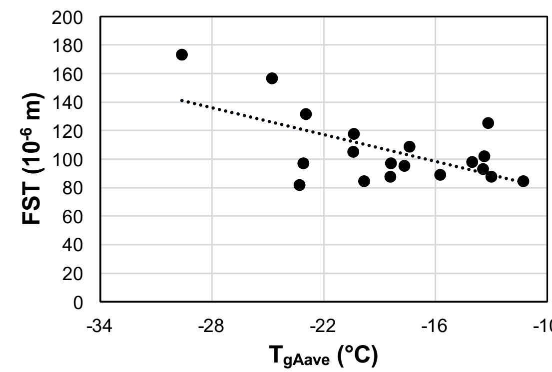
			Mixture Properties				
			Fracture Parameters				Rheological Parameters
			FI	RDCI	G_f@DCT	FST	$G\text{-}R_m$
Binder Properties	Rheological Parameters	R	0.65	0.62	0.39	0.37	0.51
		$T_c(s)$	0.46	0.48	0.25	0.30	0.52
		$T_c(m)$	0.59	0.58	0.29	0.27	0.66
		ΔT_c	0.45	0.41	0.20	0.13	0.48
		HTPG	**0.91**	**0.90**	0.11	0.16	**0.84**
		LTPG	0.48	0.49	0.27	0.30	0.54
		G-R	0.46	0.45	0.30	0.28	0.54
	DSC Parameters	$T_{g\alpha}$	0.36	0.37	0.27	0.42	0.40
		$T_{g\beta}$	0.50	0.52	0.35	0.55	0.52
		T_{gAave}	**0.73**	**0.76**	0.41	0.61	**0.78**
		φ_α	0.48	0.52	0.21	0.27	0.38
		T_g	0.44	0.44	0.35	0.49	0.48

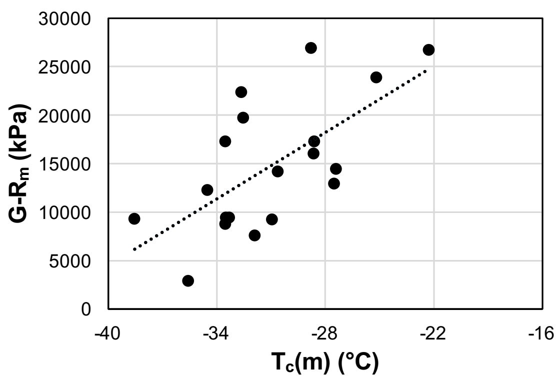
- FI, RDCI, and $G\text{-}R_m$ show the most significant correlation with binder properties
- FST from the DCT test shows good correlation with DSC (glass transition properties)
- T_{gAave} shows a better correlation with most mixture parameters

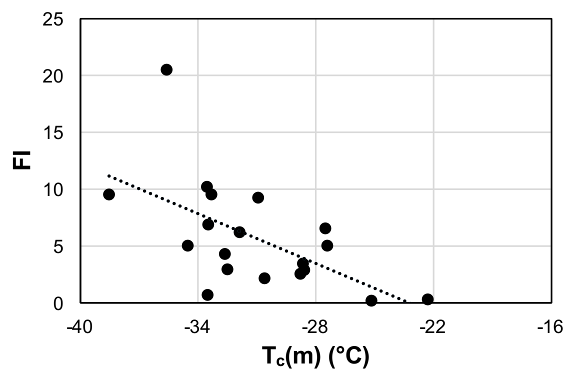
Correlation Plots: Example

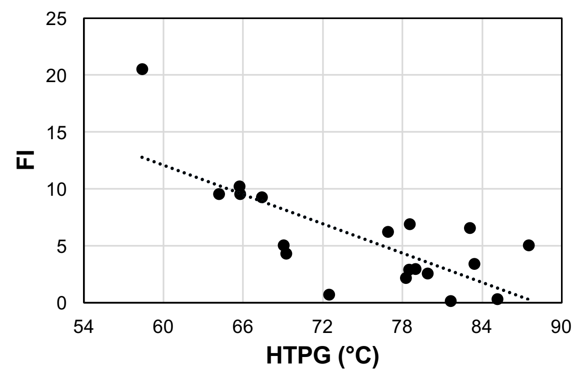












Summary

- **Rheological properties such as G-R, T_c(m), and T_g** have indicated that RAP1 is potentially incompatible, whereas RAP2 is potentially compatible, given that both RAPs have comparable PG.
- **Binder-B showed potential for inferior performance** than binder-C (both binders had similar PGs).
- DSC parameters have consensually captured potential incompatibility of RA2. Therefore, **DSC parameters are recommended** for the compatibility characterization of **RAs**.
- Results of **ΔT_c can be misleading sometimes** and thus should be evaluated **in conjunction with T_c(m)**.
- **T_{gAave} showed strong correlations with mixture fracture parameters** and can potentially be used for preliminary material screening.

Thank you for your attention!

Questions and Comments?

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