WORKSHOP ON BITUMEN EMULSION TECHNOLOGY

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High-RAP Cold and Half-Warm Mixes with Bitumen Emulsion: Mechanical Build-Up and Performance-Balanced Evaluation

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Agenda

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Study Motivation

Economic Advantage and Circularity
RAP allows the reuse of aged asphalt binder and reclaimed aggregates, reducing the demand for virgin materials and potentially lowering production costs. Cold recycling technologies can provide significant cost savings compared with conventional rehabilitation alternatives, depending on the project conditions and construction approach.

Environmental and Operational Benefits
The use of asphalt emulsions and lower-temperature technologies reduces the energy required for mixture production and placement. Lower production temperatures can also reduce fuel consumption, emissions, fumes, and odors at both the asphalt plant and the paving site.

Technical Risk of High RAP Content
Some RAP evaluations contain a highly aged binder. This condition may increase mixture stiffness but also increase susceptibility to cracking. Therefore, emulsion content, filler type, and RAP heating temperature must be evaluated based on performance, not only on strength or stiffness.

Need for performance-balanced mix design
Performance-balanced mix design provides a framework for selecting mixtures that simultaneously consider stiffness, moisture resistance, cracking tolerance, and structural performance. This approach is especially useful for evaluating recycled materials, additives, and sustainable technologies without compromising field performance.

Experimental Matrix: 100%RAP-Asphalt emulsion

Mixture type	RAP temperature	Emulsion temperature	Compaction temperature	Emulsion content	Filler	Performance tests
Cold mix	Ambient / cold RAP	Ambient	Cold compaction	4.5%	None, mineral filler, $CaCO_3$, $Ca(OH)_2$, Portland cement	Mr, IDEAL-CT, TSR
Half-warm mix	110°C	60°C	70°C	3.0%, 3.5%, 4.0%	No filler	Mr, IDEAL-CT, TSR, Dynamic Modulus
Low-temperature RAP mix	60°C	60°C	50–60°C	3.5%	No filler	Dynamic Modulus, IDEAL-CT, Fatigue 4PBT

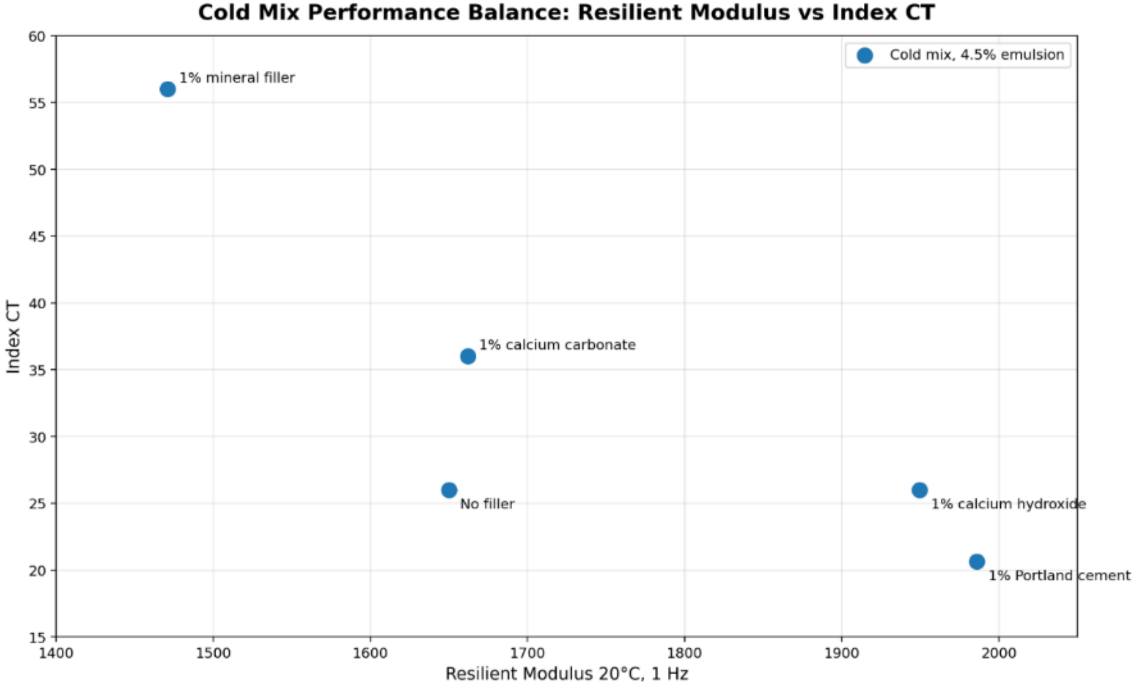
Performance data Table

Technology	Resilient Modulus, Mr 20°C 1Hz ASTM D7369-11	Index CT ASTM D8225	IDT dry , Kpa AASHTO T-283	IDT wet TSR, kPa AASHTO T-283	%TSR AASHTO T-283	Dynamic Modulus 20°C, 10 Hz
Cold mixes, 4.5% emulsion						
No filler	1650	26	418	295.77	71	---
1% mineral filler	1471	56	430.9	302.07	70	---
1% Calcium carbonate	1662	36	367.1	243.27	66	---
1% Calcium hydroxide	1949.6	26	359.9	259.93	73	---
1% Portland cement	1986	21	371	277.97	75	---
half-warm mix, % emulsion (RAP 110°C)						
3.0	3030	22	944	518.3	55	---
3.5	3106	60	771	466.3	61	4307
4.0	2461	55	617	413.7	67	---
half-warm mix, % emulsion (RAP 60°)						
3.5 (RAP 60°C)	1713	97	611	337	55	3361

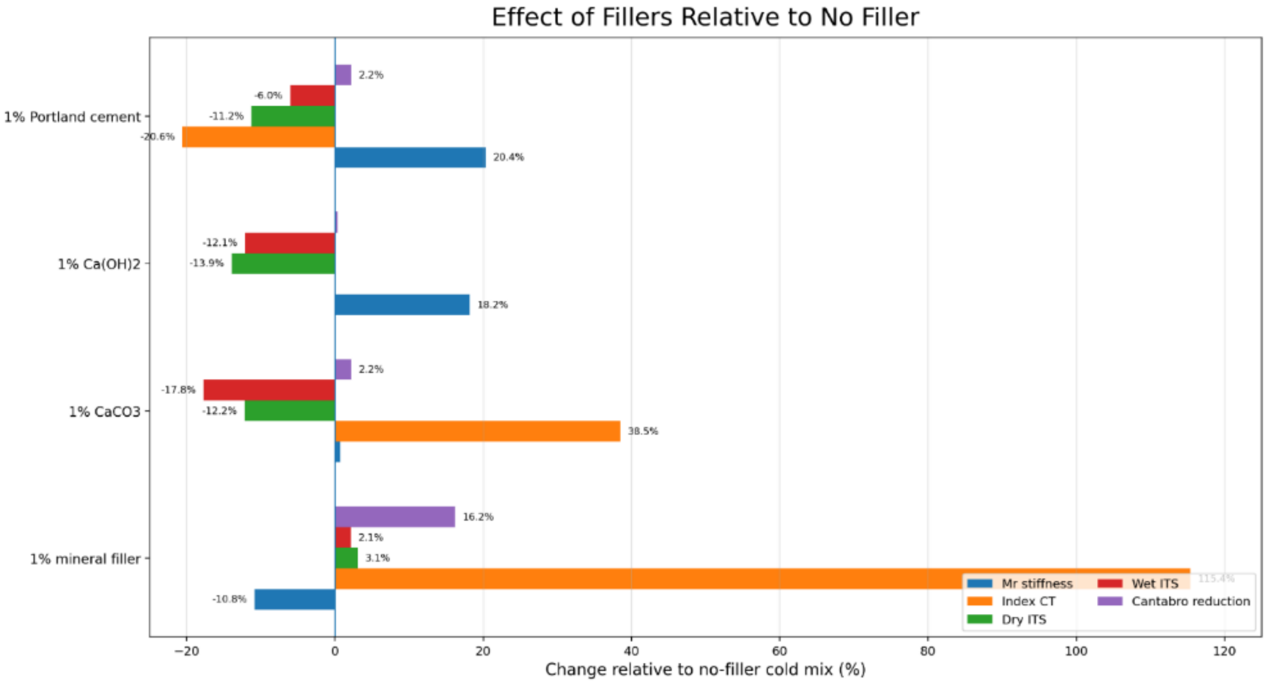
PG RAP: 95-15
Emulsion: CSS, asphalt residue: 63%
Emulsion content expressed as a percentage of dry RAP

Effect of fillers cold mix

Stiffness vs cracking tolerance



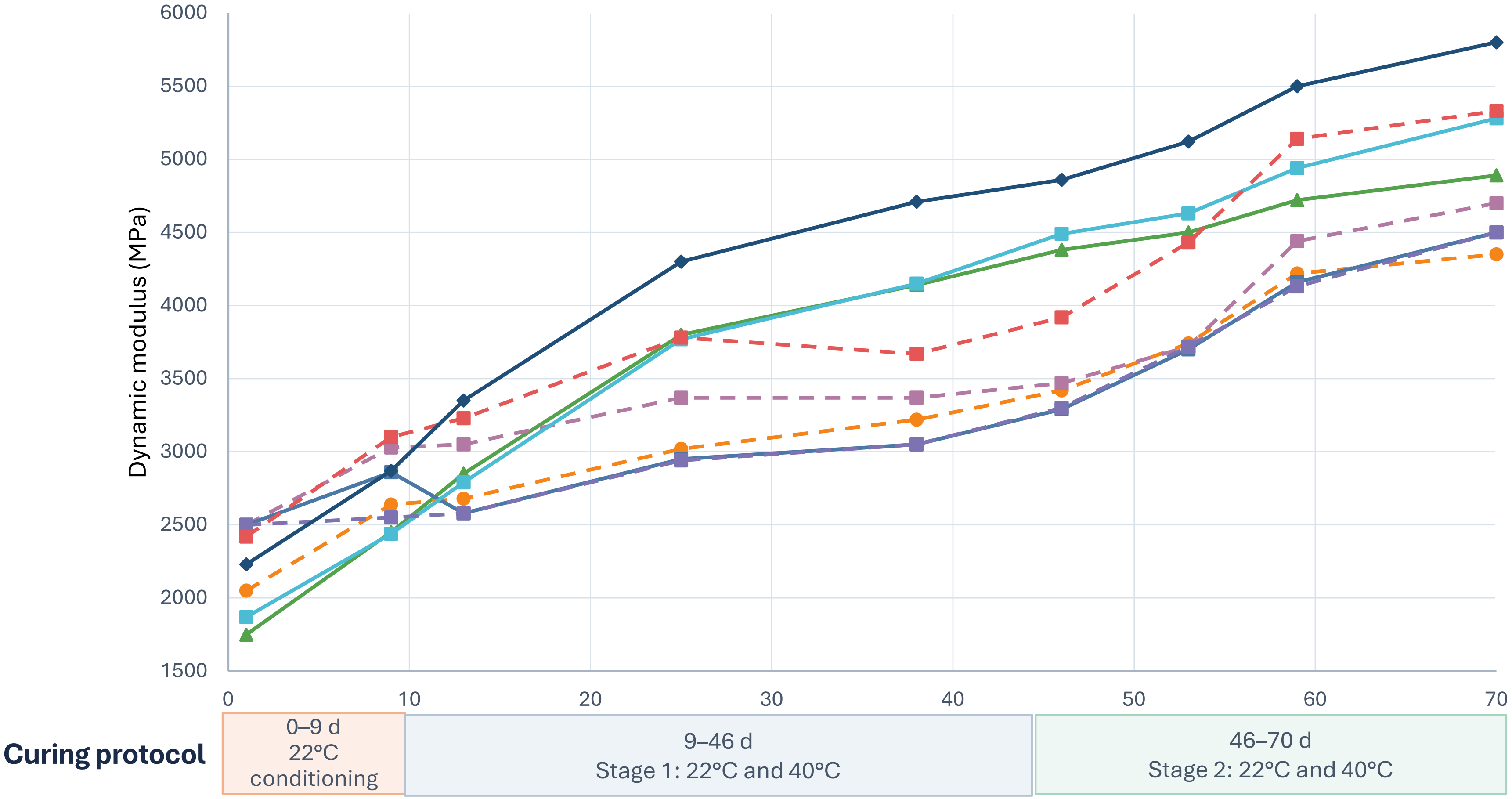
Normalize data



Positive Cantabro value = lower Cantabro loss than the no-filler control. Mr increase means stiffer, not always better for cracking. Gf was not included because it is not reported in the attached table.

Dynamic Modulus Growth During Curing

Cold mixes • specimen-level trends across 22°C and 40°C conditions



Key takeaways

- Modulus rises steadily across all specimens over 70 days.
- All mixtures increased their dynamic modulus during the curing period, regardless of curing temperature. By the end of the curing period, all specimens showed an increase of at least approximately 80% compared with their initial modulus
- Stage 2 shows a strong late gain for several 22°C specimens.

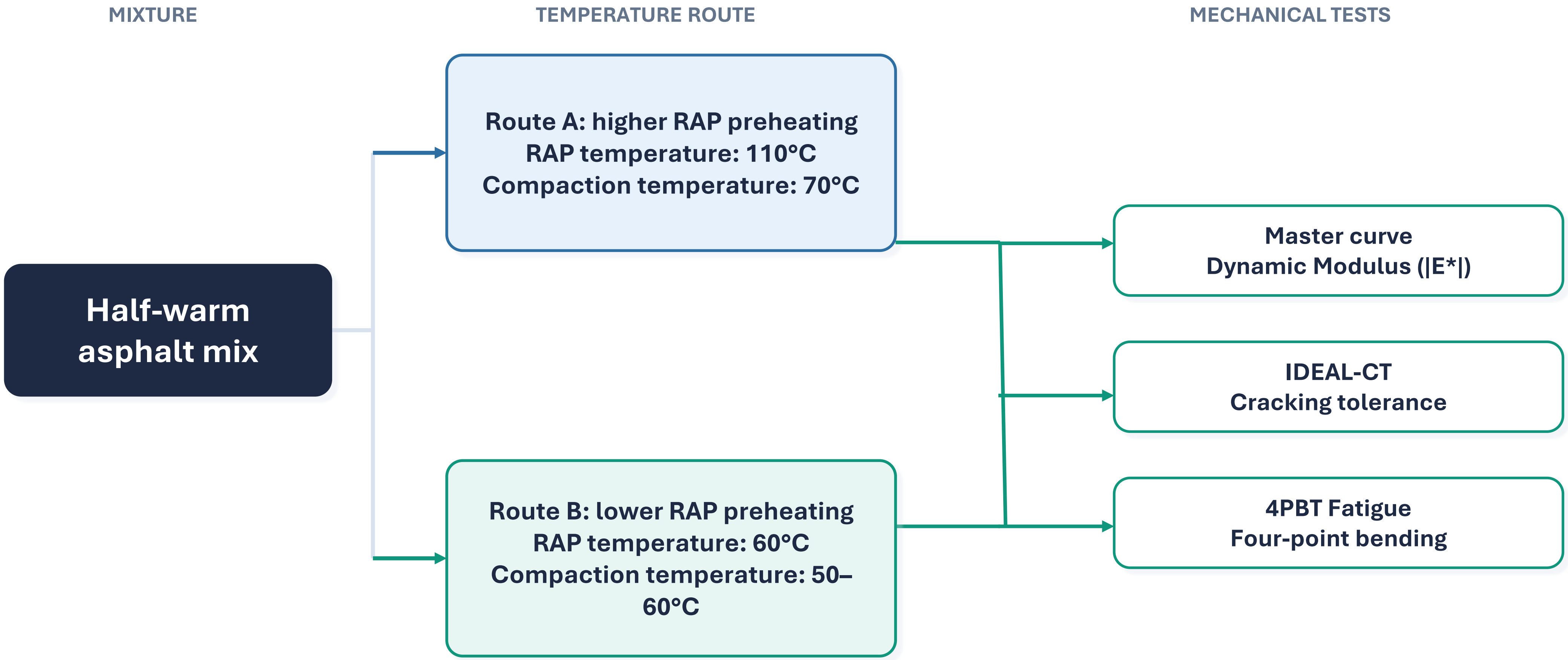
Encoding

40°C specimens

22°C specimens

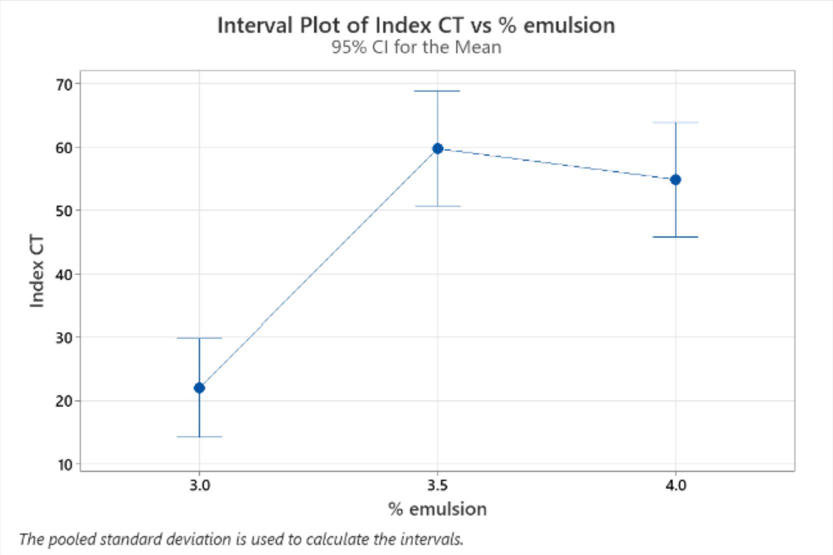
Individual specimens are shown; line style indicates curing temperature group.

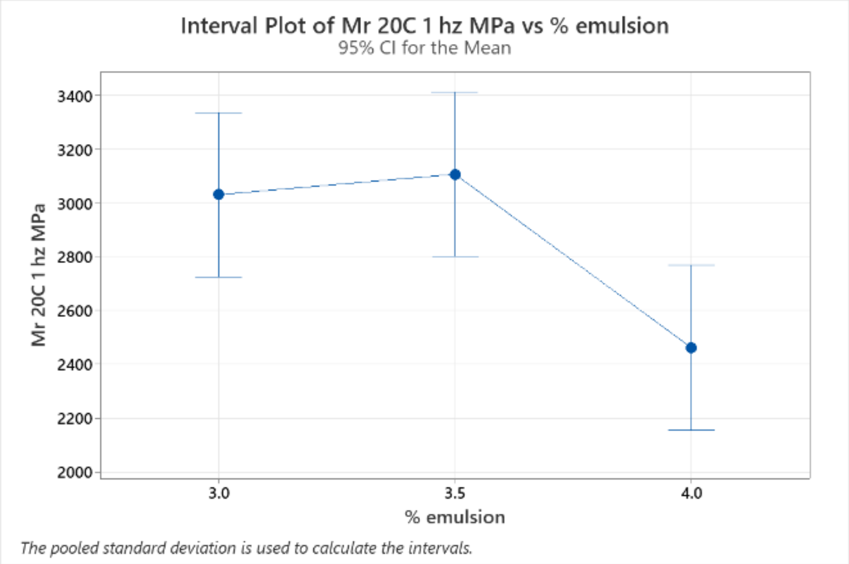
Half-Warm mix Testing Matrix

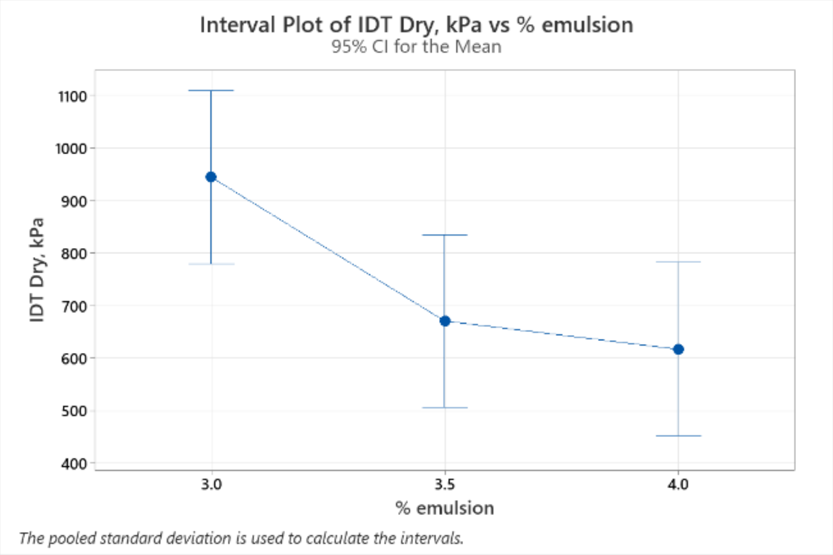


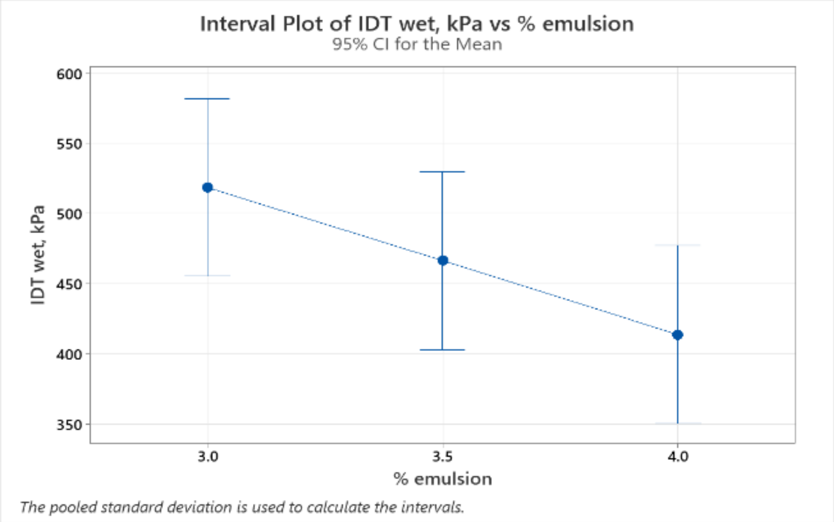
Notes: RAP = reclaimed asphalt pavement; IDEAL-CT = indirect tensile asphalt cracking test; 4PBT = four-point bending fatigue test.

Half-warm mix: optimum emulsion content





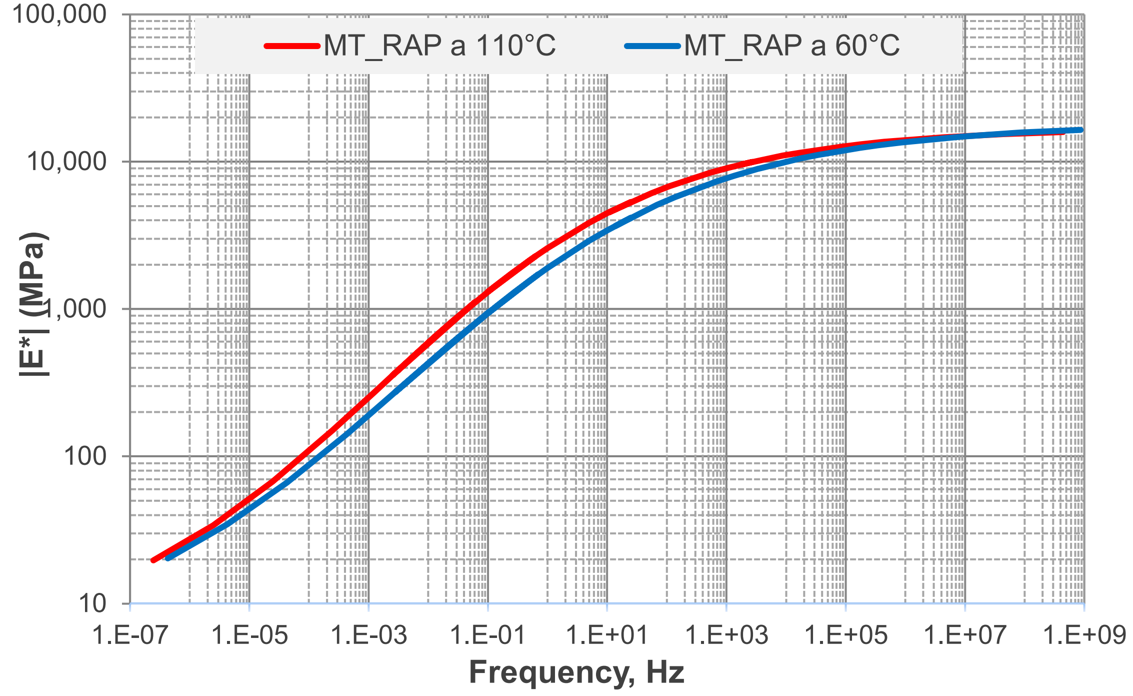




Heating temperature RAP: 110°C
Emulsion temperature: 60°C
Mix compaction temperature: 70°C

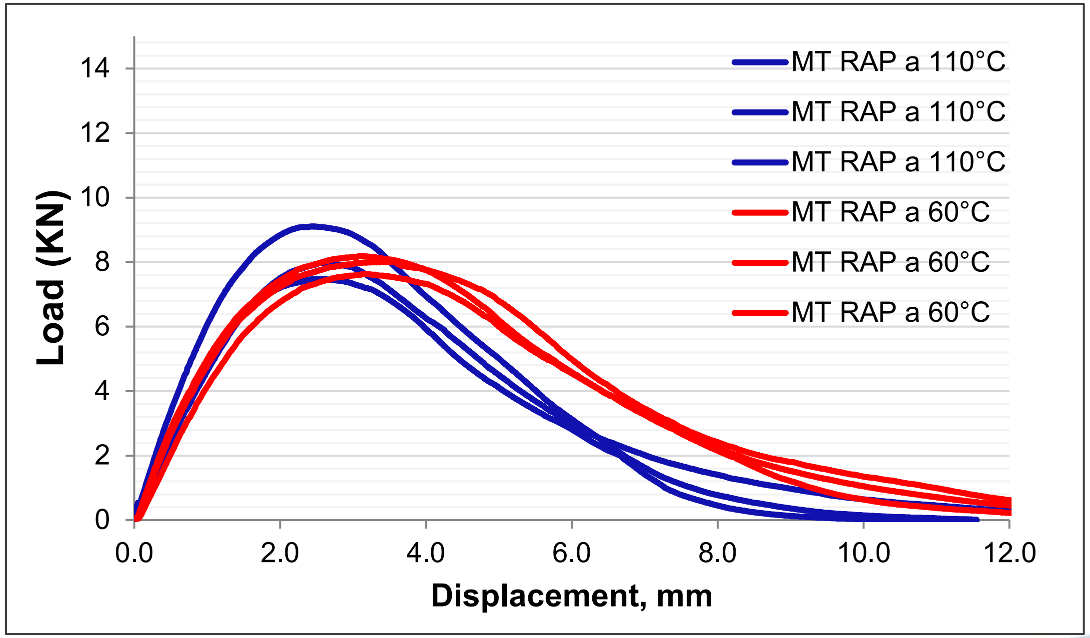
Master Curves

Dynamic modulus |E*|, at 20°C, 10Hz/ASSHTO T-42	Heating temperature RAP	|E*| (MPa) Average	δ (°) average
	110°C	**4307**	**16.7**
	60°C	**3,361**	**19.0**

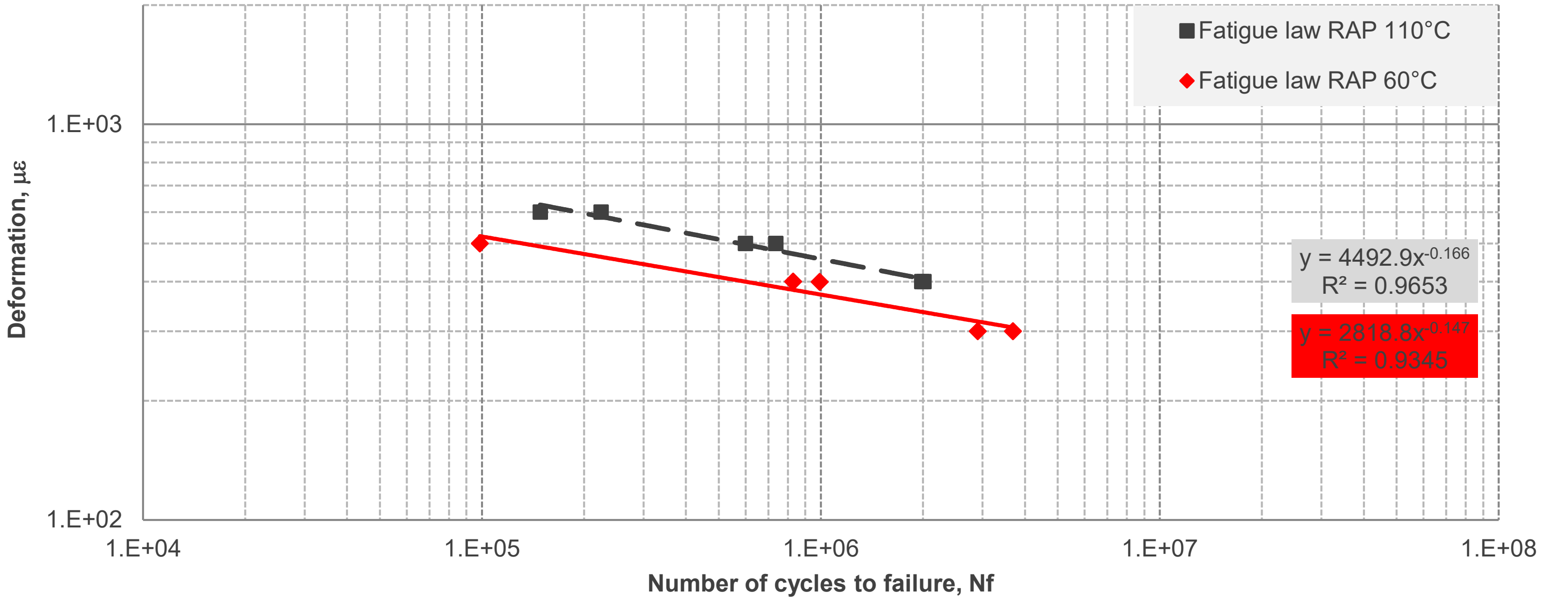


Ideal CT

Ideal CT @25°C/ASTM D8225	Index CT average	Peak load (kN) average
RAP at 110°C	59.7	8.19
RAPat 60°C	97.15	7.92



Fatigue law
Four-point Bending Test (4PBT)/ AASHTO T-321, 20°C, 10 Hz

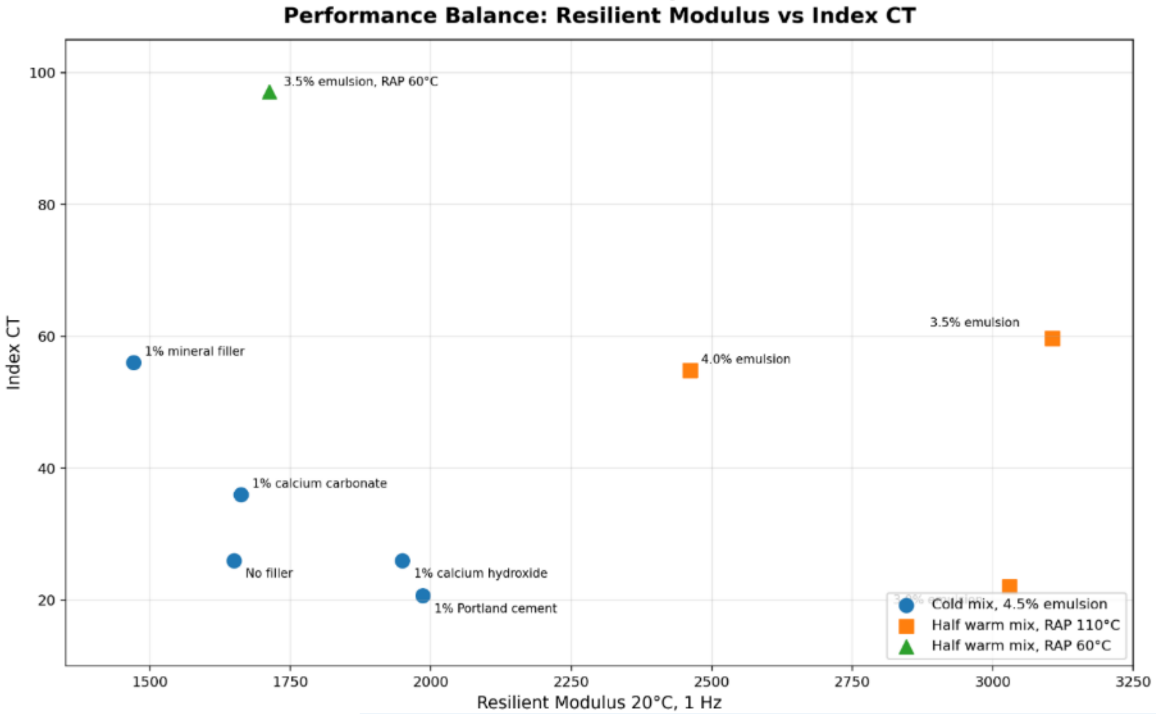


Fatigue endurance limit	
FEL MT RAP a 110°C	204
FEL MT RAP a 60°C	159

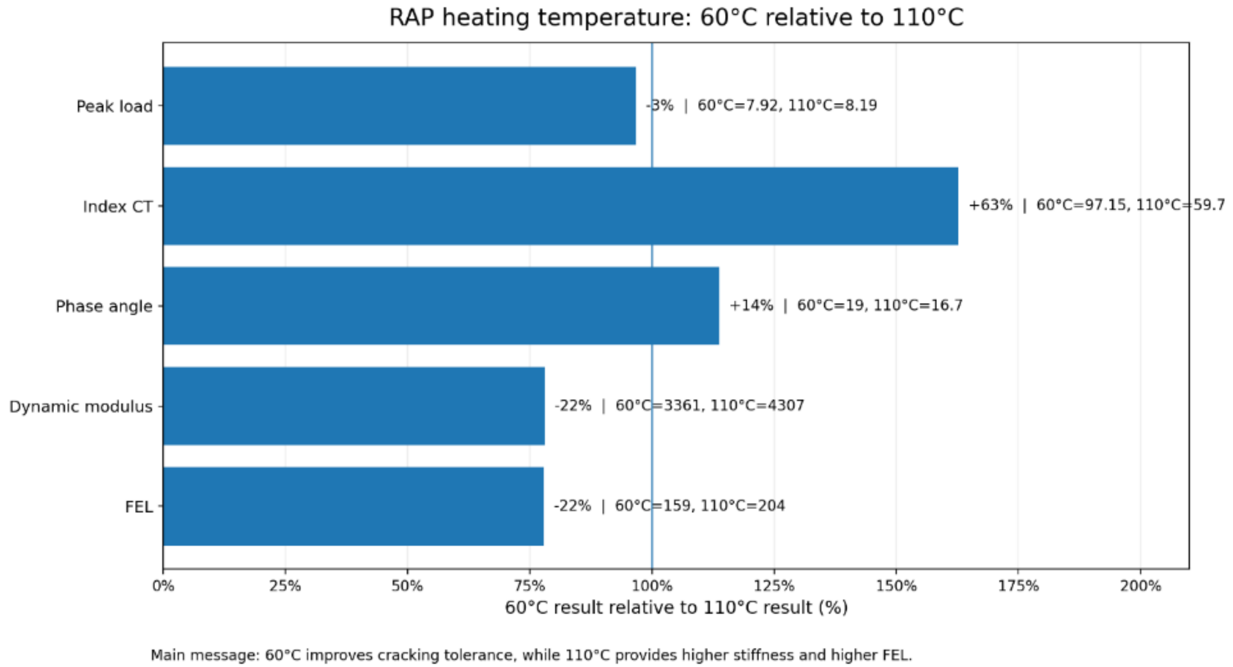
Air voids RAP 110°C: 3.8%
Air voids RAP 60°C 7.5%

Effect of RAP heating temperature

Stiffness vs cracking tolerance



Normalize data



Higher RAP heating temperature increases stiffness, while lower RAP heating temperature improves cracking tolerance.
Therefore, the optimum RAP heating temperature should be selected through a balanced mix design, not solely based on maximum modulus.

Dynamic modulus and Ideal CT half-warm mix field data: Six-Month Service

Dynamic modulus and phase angle

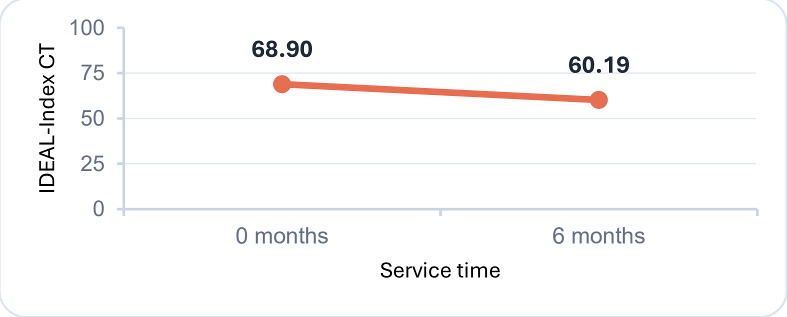
Specimen ID	Dynamic Modulus			Phase Angle		
	|E*| (MPa)	Average |E*| (MPa)	C.V. (%)	ϕ (degrees)	Average ϕ (degrees)	Std. dev. (degrees)
Km 1+500 (6 months)	4,837	4,833	4.7	13.61	13.8	0.2
Km 1+500 (6 months)	4,606			13.99		
Km 1+500 (6 months)	5,056			13.72		

Dynamic modulus trend

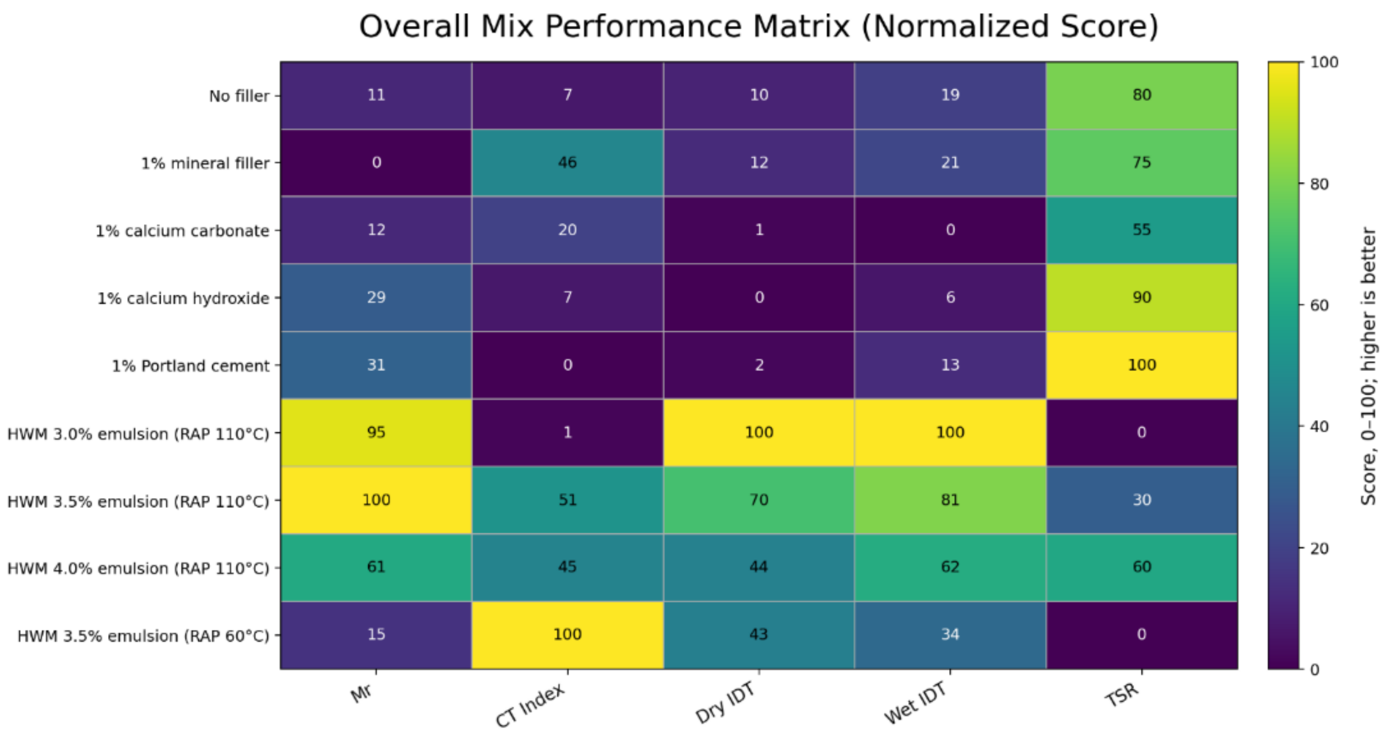
IDEAL-CT cracking tolerance test

Specimen ID	Air voids (%Va)	Peak load (kN)	IDEAL-CT index	Average IDEAL-CT index	IDEAL-CT COV (%)
N1–Layer 2	10.71%	13.73	62.50	60.19	8.07%
N2–Layer 1	11.65%	12.37	54.61		
N3–Layer 2	11.36%	11.89	63.47		

IDEAL-Index CT trend



Mixture selection by design objective



Note: Cantabro mass loss and Dynamic Modulus were removed. Scores are min–max normalized by metric; higher is better.

Design objective	Comments	Best candidates from current data
Maximize stiffness	Use when structural capacity is critical	Half-warm mix + RAP 110°C
Improve cracking resistance	Use when fatigue/cracking risk control design	Cold mix 1% mineral filler/half-warm mix + RAP 60°C
Improve moisture retention	Use TSR together with absolute wet ITS	Higher strength in wet condition- half-warm mix, RAP 110°C Higher % TSR cold mix +1% Portland cement
Balance half-warm mix design	Avoid selecting only by maximum ITS or modulus	Half-warm + RAP 60°C

Conclusions

- Filler selection in cold mixtures strongly affects the stiffness–cracking trade-off.

- High-RAP emulsion mixtures are feasible under the evaluated materials, curing conditions, and performance criteria

- The curing results confirm that emulsion-based RAP mixtures develop mechanical properties progressively, showing clear stiffness build-up as curing time and temperature increase.

- RAP heating temperature is a critical design variable: 110°C increased stiffness, while 60°C improved IDEAL-CT cracking tolerance, although fatigue performance was not improved

THANKS

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