WESTERN REGIONAL SUPERPAVE CENTER

ARC
Asphalt Research Consortium

University of Nevada Reno

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Manitoba – PTH 8 RAP Field Sections
Update on Laboratory Test Results

Recycled Asphalt Pavement Expert Task Group

Oklahoma City, Oklahoma – October 26, 2010

Manitoba RAP Sections (PTH8)

- Provincial Highway 8 between Gimli & Hnausa, Manitoba, Canada.
- Total Project length: 17 miles
- Comparative pavement site: ~ 6 miles
- Construction date: Sept. 2009
- RAP: ½" NMAS

Heaviest Traffic lane

	About 3 km	About 3 km	About 3 km	1 - 3 km
2"	HMA/50% RAP 4th lift	HMA/50% RAP 4th lift with grade change	HMA/15% RAP 4th lift	HMA/No RAP 4th lift
2"	HMA/50% RAP 3rd lift	HMA/50% RAP 3rd lift with grade change	HMA/15% RAP 3rd lift	HMA/No RAP 3rd lift
	New HMA/50% RAP 2nd lift			
	New HMA/50% RAP 1st lift			

Manitoba RAP Sections (PTH8)

Mixtures Types

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Mixture	Binder	Field Mix Lab Compacted	Lab Mix Lab Compacted
0% RAP no grade change	Pen 150-200	F-0%-150	L-0%-150
15% RAP no grade change	Pen 150-200	F-15%-150	L-15%-150
50% RAP no grade change	Pen 150-200	F-50%-150	L-50%-150
50% RAP grade change	Pen 200-300	F-50%-200	L-50%-200

Manitoba RAP Sections (PTH8)

Mixtures Types

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Mixture	Mix Design	Lift	Optimum Binder Content	Binder Content by Ignition Oven	RAP Binder %*
F-0%-150	Bit B	4	5.2%	5.0%	--
F-15%-150	Bit B	4	5.2%	5.1%	13.8%
F-50%-150	Bit B	4	5.0%	4.8%	49.0%
F-50%-200	Bit B	4	5.0%	4.8%	49.0%
L-0%-150	Bit B	4	5.2%	--	--
L-15%-150	Bit B	4	5.2%	--	13.6%
L-50%-150	Bit B	4	5.0%	--	47.0%
L-50%-200	Bit B	4	5.0%	--	47.0%

* Based on RAP binder content of 4.7% (from Ignition Oven)

Manitoba RAP Sections (PTH8)

Test Experiment Matrix – Binders

- Determine PG grading for:
  - virgin binders:
    - Pen 150-200, Pen 200-300
  - recovered binders (85% Toluene + 15% Ethanol):
    - F-0%-150, F-15%-150, F-50%-150, F-50%-200
    - L-0%-150, L-15%-150, L-50%-150, L-50%-200
    - RAP-100%

Manitoba RAP Sections (PTH8)

Test Experiment Matrix – Binders

- Evaluate the following:
  - Blending chart process
  - RAP mortar procedure (UWM)
  - Predicted binder properties from Hirsh model
  - Predicted binder properties from Huet-Sayegh modified model (2S2P1D model)
  - Predicted binder properties from Lytton et al. model

Manitoba RAP Sections (PTH8)

Test Experiment Matrix – Mixtures

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Property	F-0%-150	F-15%-150	F-50%-150	F-50%-200	L-0%-150	L-15%-150	L-50%-150	L-50%-200
Resistance to Moisture Damage								
- TS vs. F-T cycles: 0, 1 and 3 F-T	X	X	X	X	X	X	X	X
- TSR at 1 and 3 F-T	X	X	X	X	X	X	X	X
- E* vs. F-T cycles: 0, 1 and 3 F-T	X	X	X	X	X	X	X	X
Resistance to Thermal Cracking								
- TSRST: 0 and 3 F-T	X	X	X	X	X	X	X	X
Resistance to Fatigue Cracking	X	X	X	X	X	X	X	X

Extraction/Recovery Using Centrifuge

Superpave PG Grades

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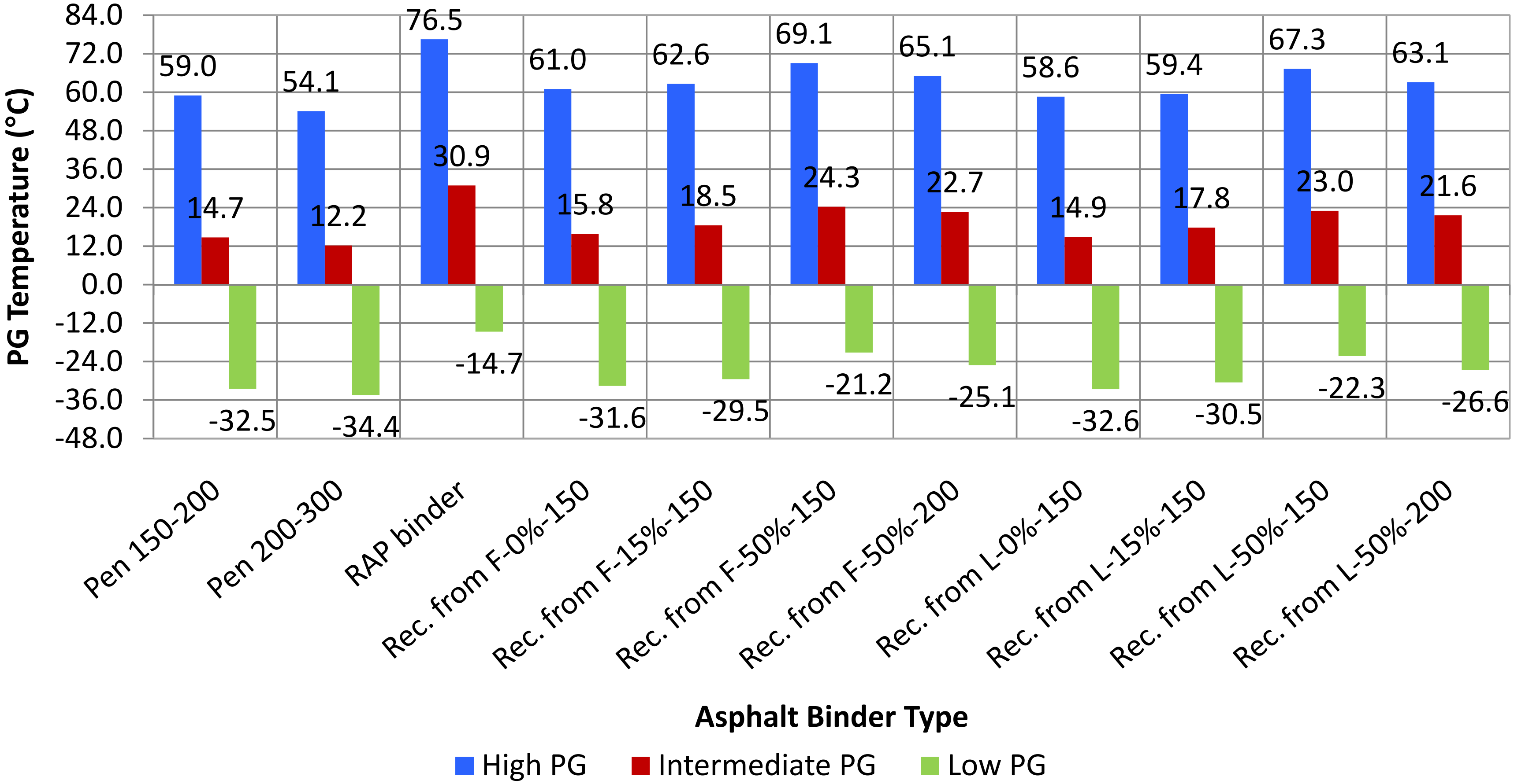

Extraction/Recovery Using Centrifuge

Superpave PG Grades

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	Mix	PG Grade
Virgin	PEN150-200	58-28
	PEN200-300	52-34
Extr./ Rec. using centrifuge	F-0%-150	58-28
	F-15%-150	58-28
	F-50%-150	64-16
	F-50%-200	64-22
	L-0%-150	58-28
	L-15%-150	58-28
	L-50%-150	64-22
	L-50%-200	58-22
	RAP binder (AASHTO M320)	76-10

Asphalt Binder Blending Chart

High Critical Temperature

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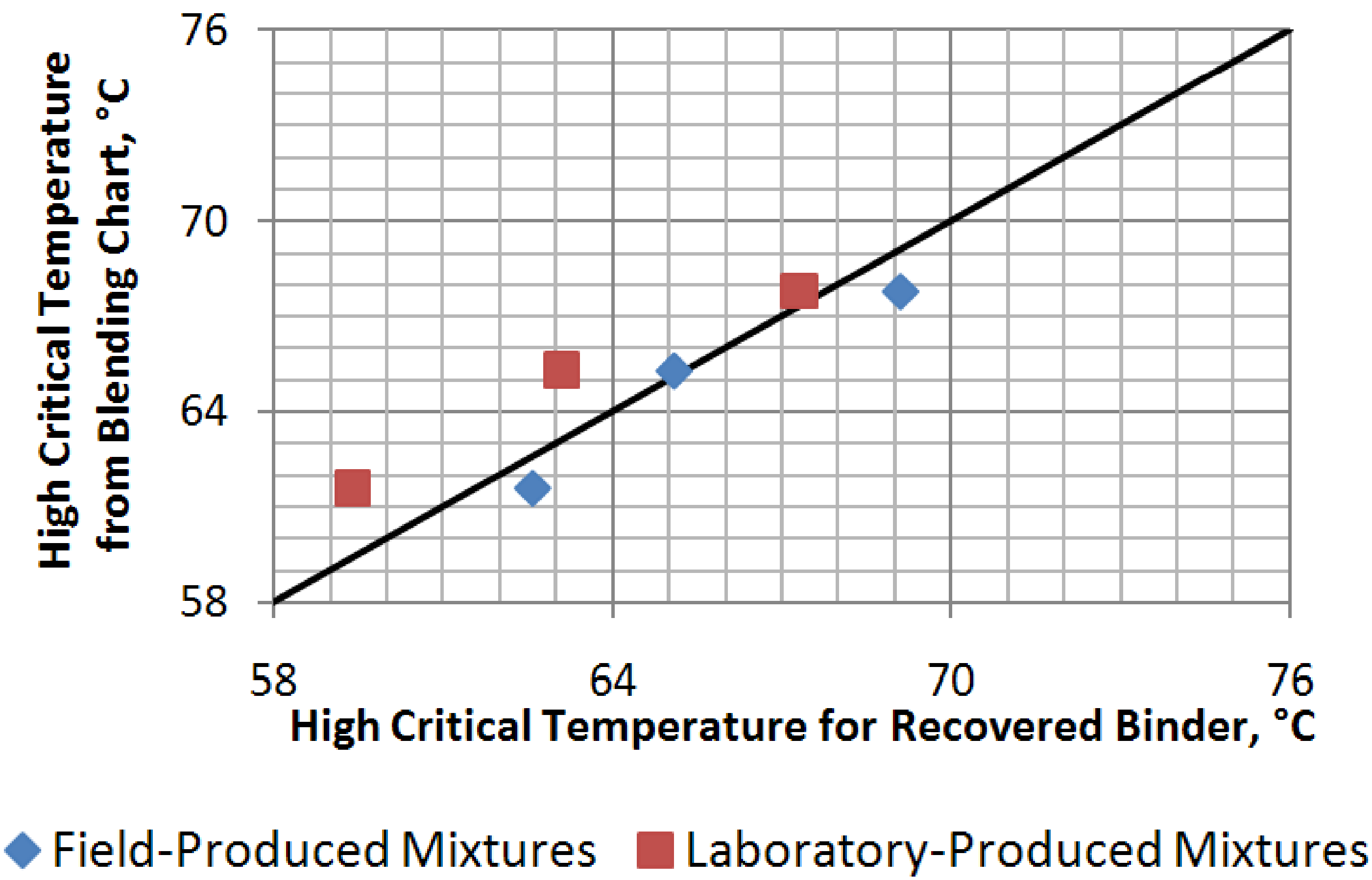
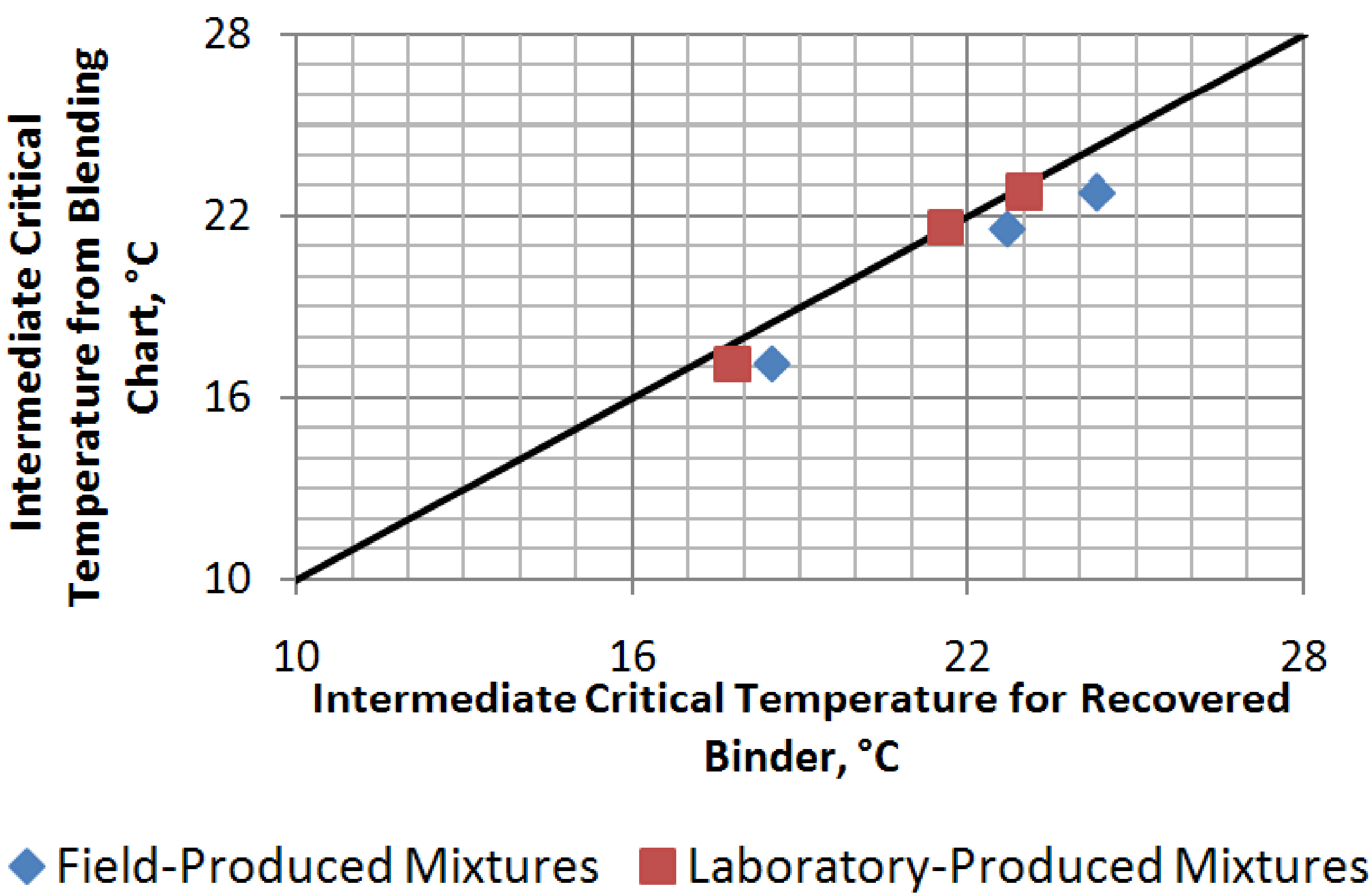


Asphalt Binder Blending Chart

Intermediate Critical Temperature



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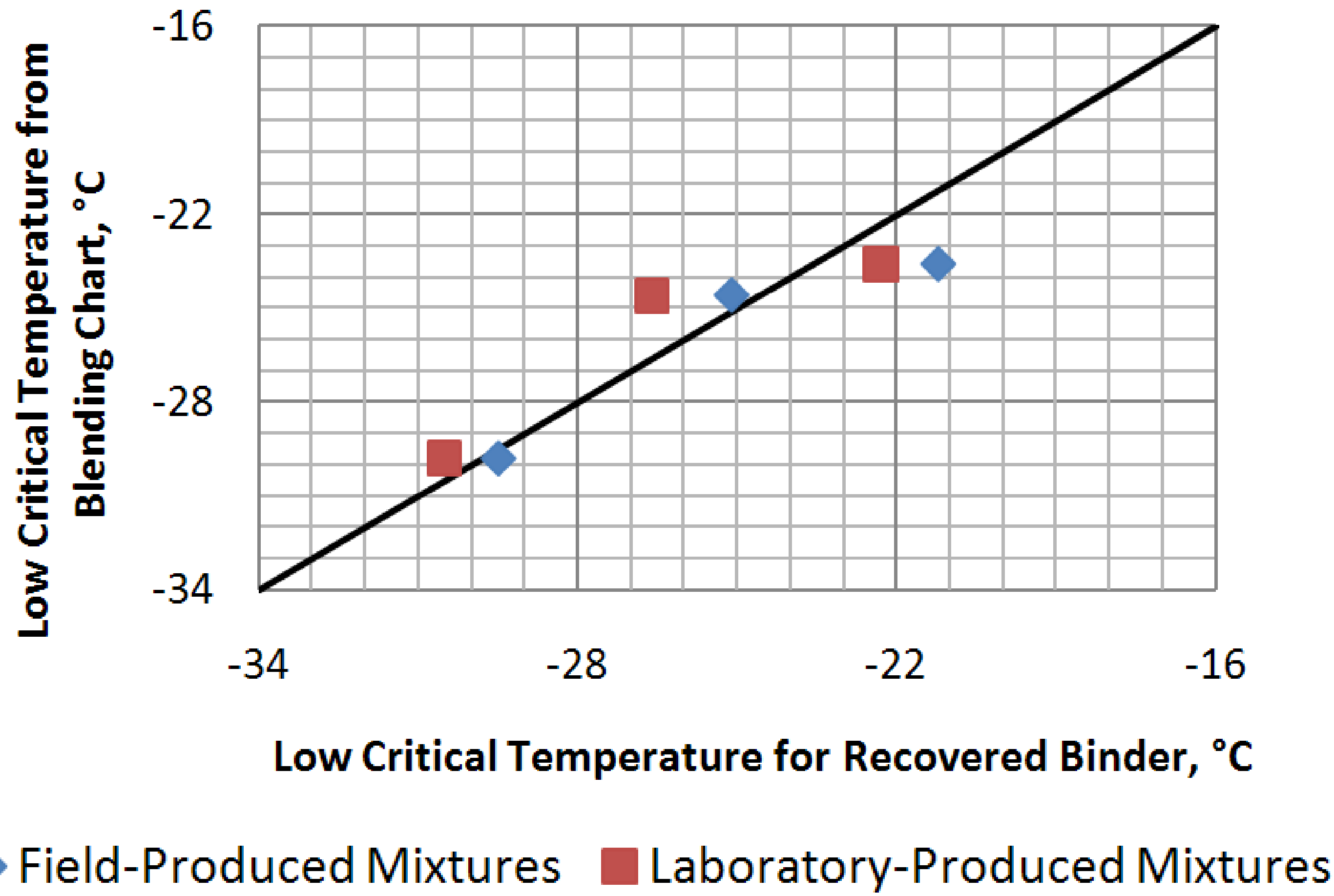
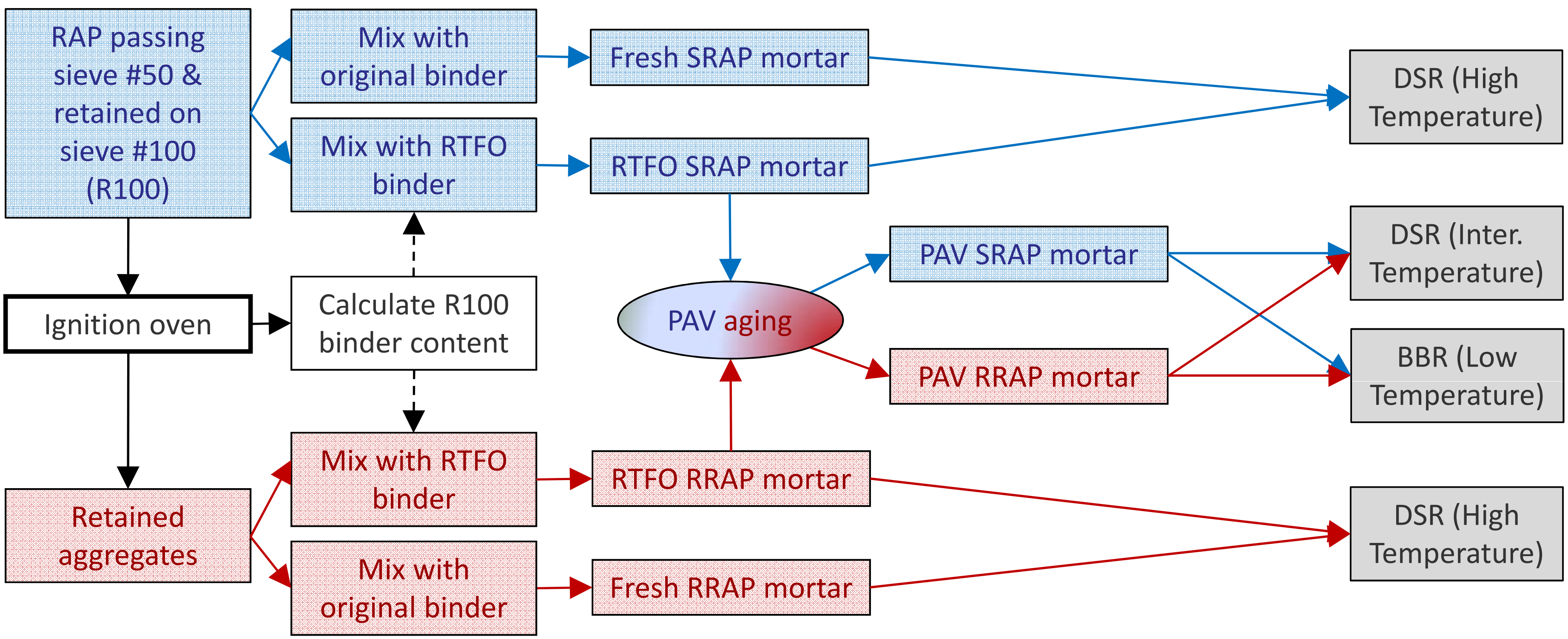
Asphalt Binder Blending Chart

Low Critical Temperature



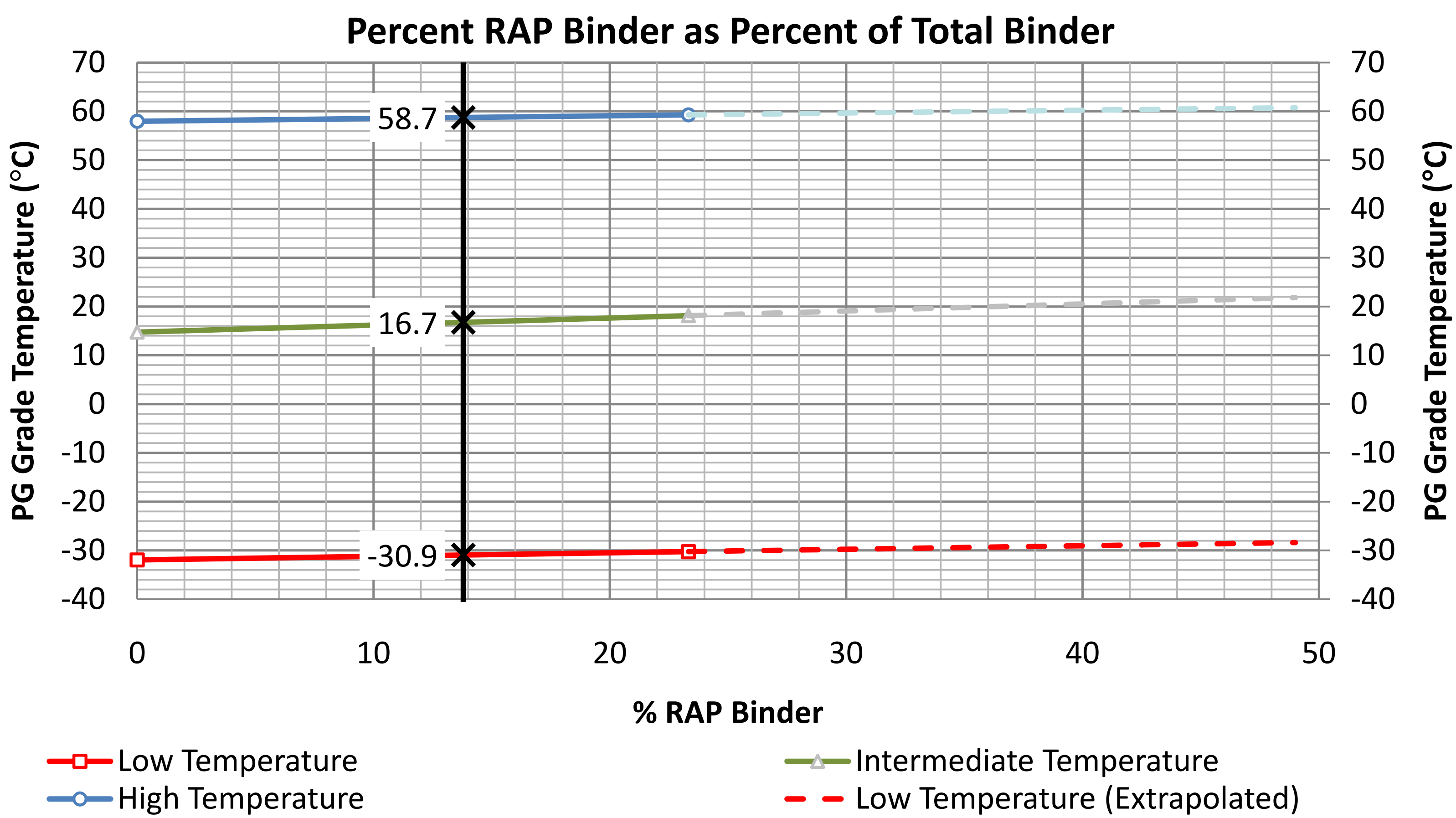
RAP Mortar Procedure (UWM)

Flow Chart of Material Preparation and Testing



RAP Mortar Procedure (UWM)

Typical Results



Predictions Using Hirsh Model

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- Use semi-empirical model proposed by Christensen et al. (2003) to estimate shear dynamic modulus.
- Measured E* laboratory data used.
- Minimize Error between Hirsch model prediction and real data by varying binder stiffness.
- Compare estimated stiffness with measured stiffness.
- Determine binder critical temperature.

Summary of PG Grades

Preliminary Results for Pen 150-200

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% RAP	Mix	Critical T_{High}				Critical $T_{Intermediate}$				Critical T_{Low}				TSRST
		Rec.	Blend Chart	Hirsh	Mortar Testing	Rec.	Blend Chart	Hirsh	Mortar Testing	Rec.	Blend Chart	Hirsh	Mortar Testing	
Virgin Binder		59.0				14.7				-32.5				--
0	F	61.0	--	IP	--	15.8	--	IP	--	-31.6	--	--	--	-32.8
	L	58.6	--	57.5		14.9	--	16.0		-32.6	--	--		-33.0
15	F	62.6	63.6	IP	58.7	18.5	18.1	IP	16.7	-29.5	-29.1	--	-30.9	-30.8
	L	59.4	61.3	57.6		17.8	18.3	18.6		-30.5	-29.3	--		-30.9
50	F	69.1	68.8	IP	61.0	24.3	23.4	IP	21.8	-21.2	-23.2	--	-28.4	-29.1
	L	67.3	67.6	62.5		23.0	23.7	24.0		-22.3	-23.7	--		-27.2

Summary of PG Grades (cont'd)

Preliminary Results for Pen 200-300

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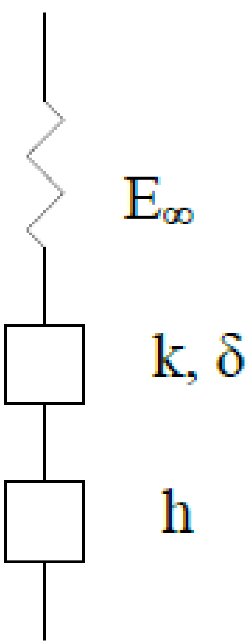
% RAP	Mix	Critical T_{High}				Critical $T_{Intermediate}$				Critical T_{Low}				TSRST
		Rec.	Blend Chart	Hirsh	Mortar Testing	Rec.	Blend Chart	Hirsh	Mortar Testing	Rec.	Blend Chart	Hirsh	Mortar Testing	
Virgin Binder		54.1				12.2				-34.4				--
0*	F	61.0	--	IP	--	15.8	--	IP	--	-31.6	--	--	--	-32.8
	L	58.6	--	57.5		14.9	--	16.0		-32.6	--	--		-33.0
50	F	65.1	65.3	IP	57.0	22.9	21.6	IP	18.8	-25.1	-24.6	--	-31.4	-32.1
	L	63.1	63.2	64.1		21.6	21.8	20.1		-26.6	-24.5	--		-34.4

*0% RAP manufactured with Pen150-200

Inverse Problem for Low Temp Characterization

A. C. Falchetto, M. O. Marasteanu & H. Di Benedetto

- **Huet Model (Huet 1963)**



$$D(t) = \frac{1}{E_\infty}\left(1 + \delta\frac{(t/\tau)^k}{\Gamma(k+1)} + \frac{(t/\tau)^h}{\Gamma(h+1)}\right)$$

$$E^*(i\omega\tau) = \frac{E_\infty}{1 + \delta(i\omega\tau)^{-k} + (i\omega\tau)^{-h}}$$

$D(t)$	creep function
E^*	complex modulus,
E_∞	glassy modulus,
h, k	exponents such that $0<k<h<1$
δ	dimensionless constant,
ω	2π*frequency,
τ	characteristic time varying with temperature
t	time
Γ	gamma function:

Inverse Problem for Low Temp Characterization

A. C. Falchetto, M. O. Marasteanu & H. Di Benedetto

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- **Calculated $S(t)_{binder}$ from measured $S(t)_{mixture}$**

$$S_{mix}(t) = S_{binder}(t/10^{\alpha})\frac{E_{\infty\_mix}}{E_{\infty\_binder}}$$

$$\tau_{binder} = 10^{-\alpha}\,\tau_{mix}$$

$S_{mix}(t)$	creep stiffness of mixture,
$S_{binder}(t)$	creep stiffness of binder,
E_{∞_mix}	glassy modulus of mixture,
E_{∞_binder}	glassy modulus of binder,
α	regression parameter which may depend on mix design,
t	time

- **Authors showed very good predictions for the binder stiffness from the mixture stiffness.**

Huet-Sayegh Modified

2S2P1D Model (Olard and Di Benedetto, 2003)

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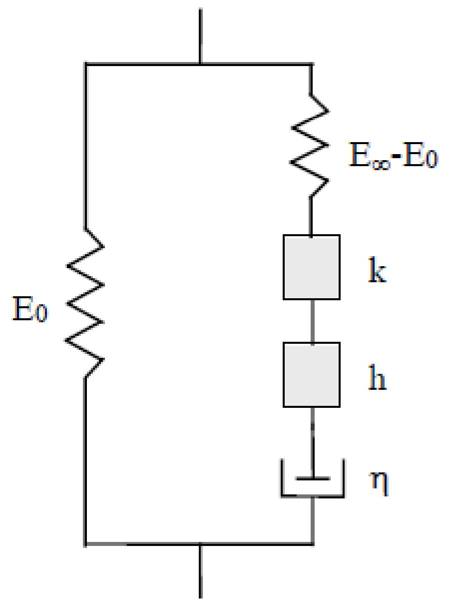
- **Generalization of Huet-Sayegh model**



$$E^*(i\omega\tau) = E_0 + \frac{E_\infty - E_0}{1 + \delta(i\omega\tau)^{-k} + (i\omega\tau)^{-h} + (i\omega\beta\tau)^{-1}}$$

i : complex number,

ω: 2π*frequency

k, h : exponents such as 0<k<h<1,

δ : dimensionless constant

E_0 the static modulus when $\omega \rightarrow 0$,

E_∞ the glassy modulus when $\omega \rightarrow \infty$,

η : Newtonian viscosity, $\eta = (E_\infty - E_0).\beta.\tau$; when $\omega \rightarrow 0$,

then $E^*(i\omega\tau) \sim E0 + i\omega.(E\infty - E0).\beta.\tau$; β is dimensionless.

τ : characteristic time varying with temperature

Huet-Sayegh Modified

2S2P1D Model (Olard and Di Benedetto, 2003)

- **Relationship between the characteristic time of the mixture and the characteristic time of the corresponding binder at the reference temperature:**

$$\tau_{mix}(T) = 10^{\alpha}.\tau_{binder}(T)$$

α: **Regression coefficient depending on mixture & aging**

Huet-Sayegh Modified

2S2P1D Model (Olard and Di Benedetto, 2003)

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- **Relationship between mix and binder complex moduli was proposed**

$$E^*_{binder}(i\omega\tau_{binder}) = E_{0\_binder} + \frac{E_{\infty\_binder} - E_{0\_binder}}{1 + \delta(i\omega\tau_{binder})^{-k} + (i\omega\tau_{binder})^{-h} + (i\omega\beta\tau_{binder})^{-1}}$$

$$E^*_{mix}(i\omega\tau_{mix}) = E_{0\_mix} + \frac{E_{\infty\_mix} - E_{0\_mix}}{1 + \delta(i\omega\tau_{mix})^{-k} + (i\omega\tau_{mix})^{-h} + (i\omega\beta\tau_{mix})^{-1}}$$

$$E^*_{mix}(\omega, T) = E_{0\_mix} + \left[E^*_{binder}(10^{\alpha}\omega, T) - E_{0\_binder}\right]\frac{E_{\infty\_mix} - E_{0\_mix}}{E_{\infty\_binder} - E_{0\_binder}}$$

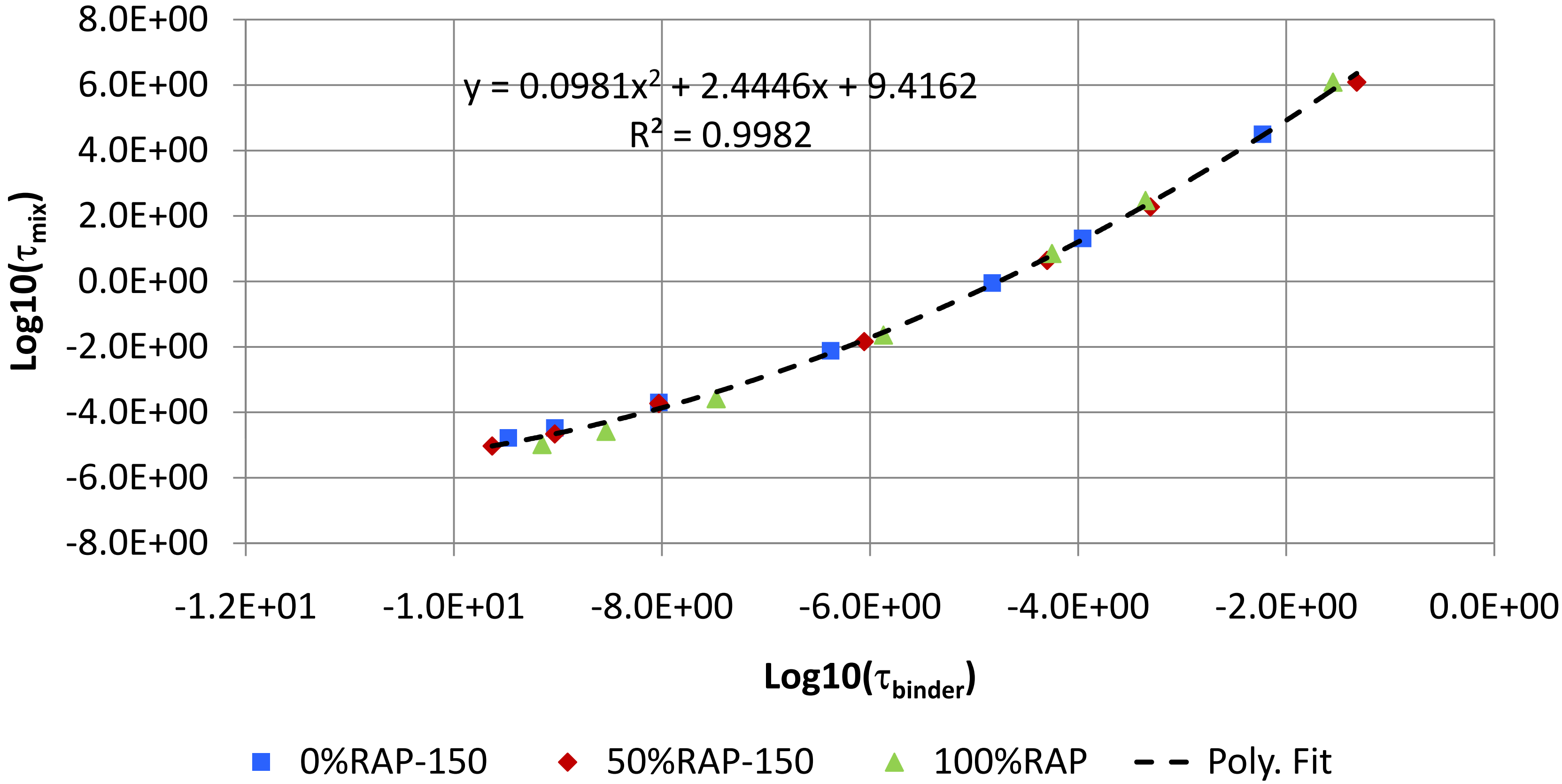
Predictions Using Huet-Sayegh Modified

Approach – Forward Calculation

- **Measure complex modulus for the various mixtures & their associated recovered asphalt binders.**
- **Fit Huet-Sayegh Modified (2S2P1D) model to measured E* data:**
  - **Determine δ, h, k, β and τ_0 for binder and mix**
- **Examine the relationship between log(τmix) & log(τbinder)**

Predictions Using Huet-Sayegh Modified

Lab-Produced mixtures



Note: not the same parameters (δ, k, and h) were used for the mixes and binders

Predictions Using Huet-Sayegh Modified

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- Promising results if relationship was found to be a unique relationship
- Continuing Effort:
  - Refine the analysis for lab-produced mixtures
  - Conduct the same analysis for field-produced mixtures
  - Conduct the same analysis for other mixtures
  - Evaluate the inverse calculation

Mixtures Testing

- TS and TSR at multiple F-T cycles
- |E*| at multiple F-T cycles
- TSRST at multiple F-T cycles
- Fatigue testing

TS at 77°F and 0, 1 and 3 F-T

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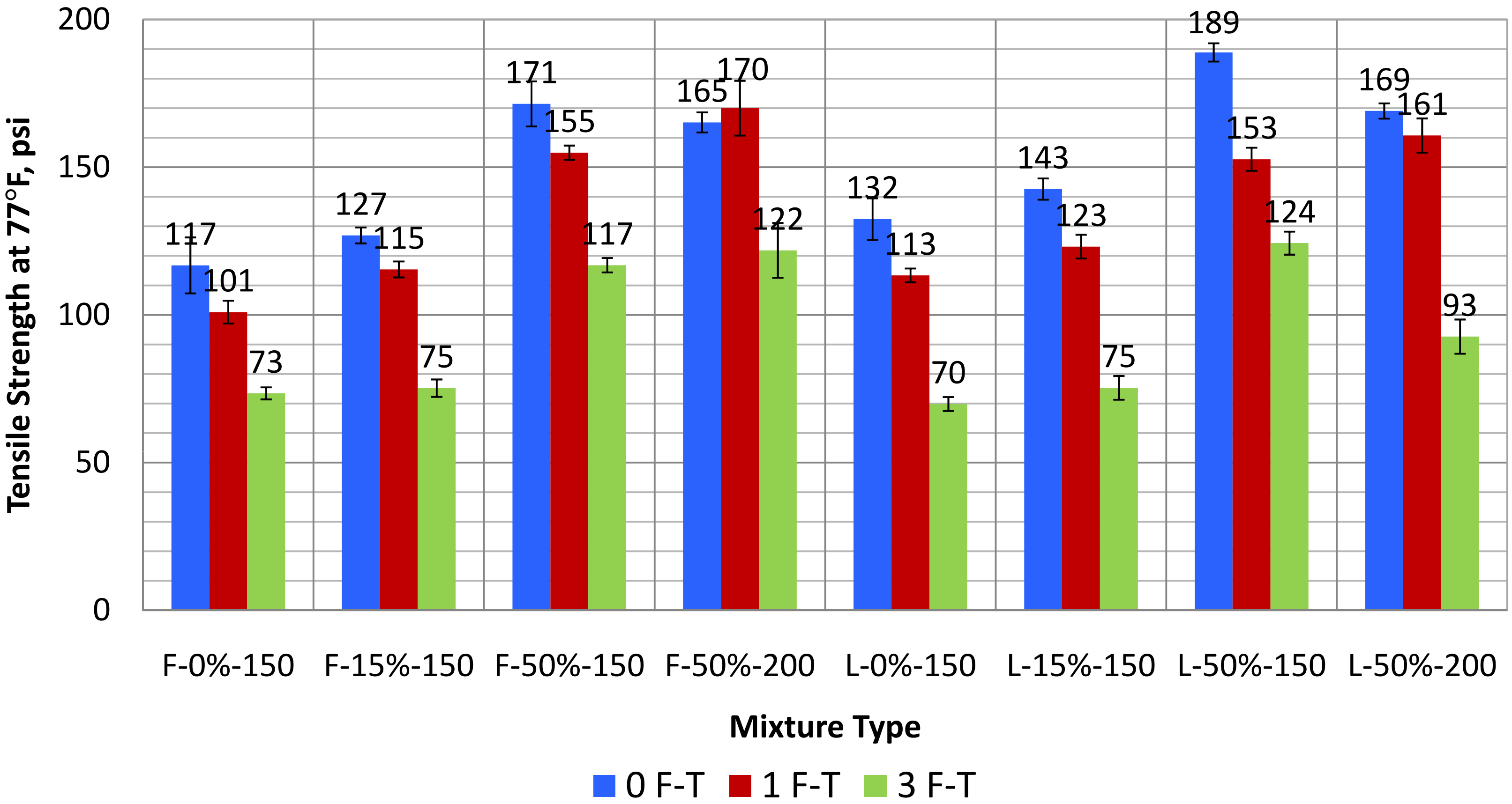
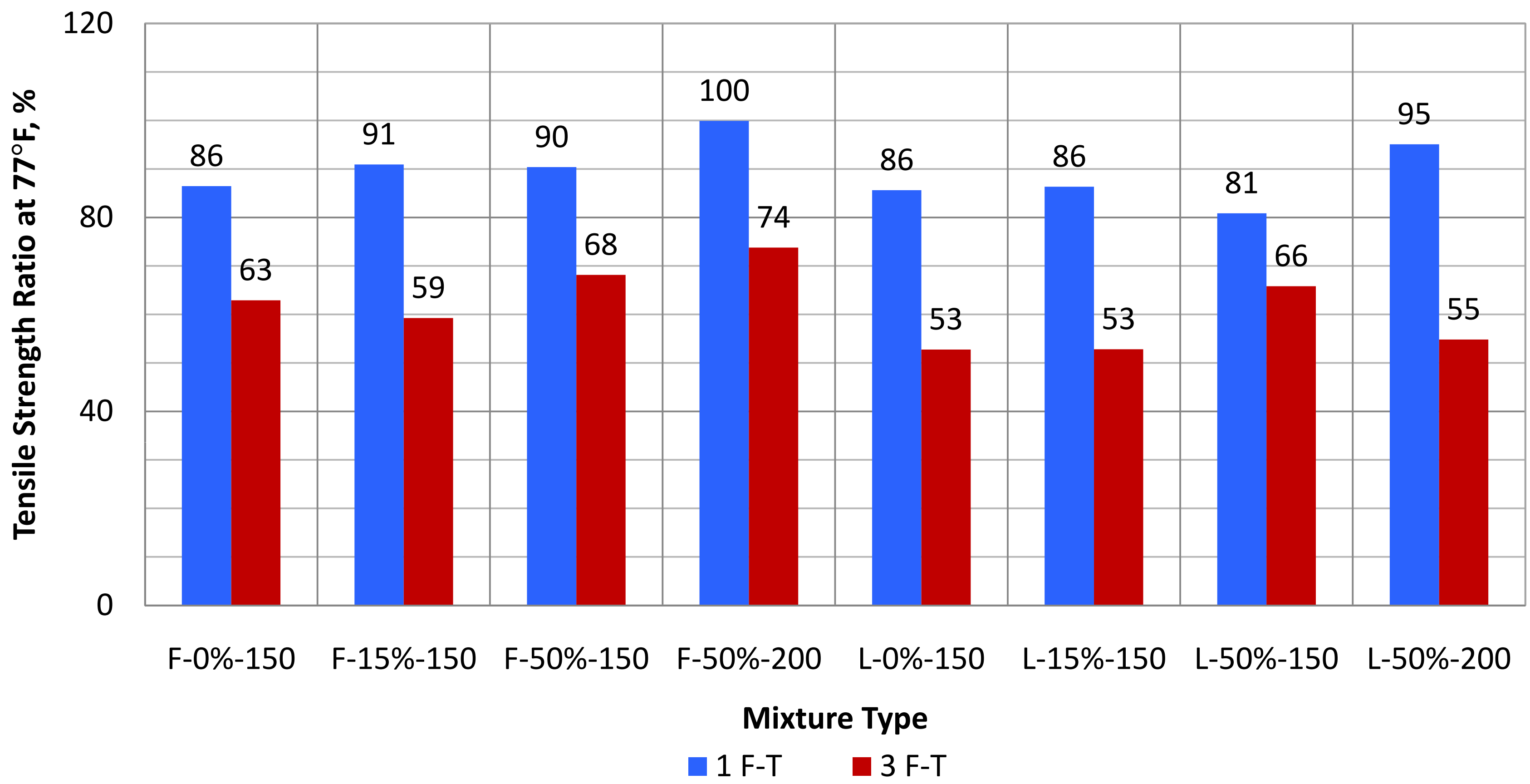


TSR at 77°F, 1 and 3 F-T



Resistance to Moisture Damage

E Test Results at 77°F*

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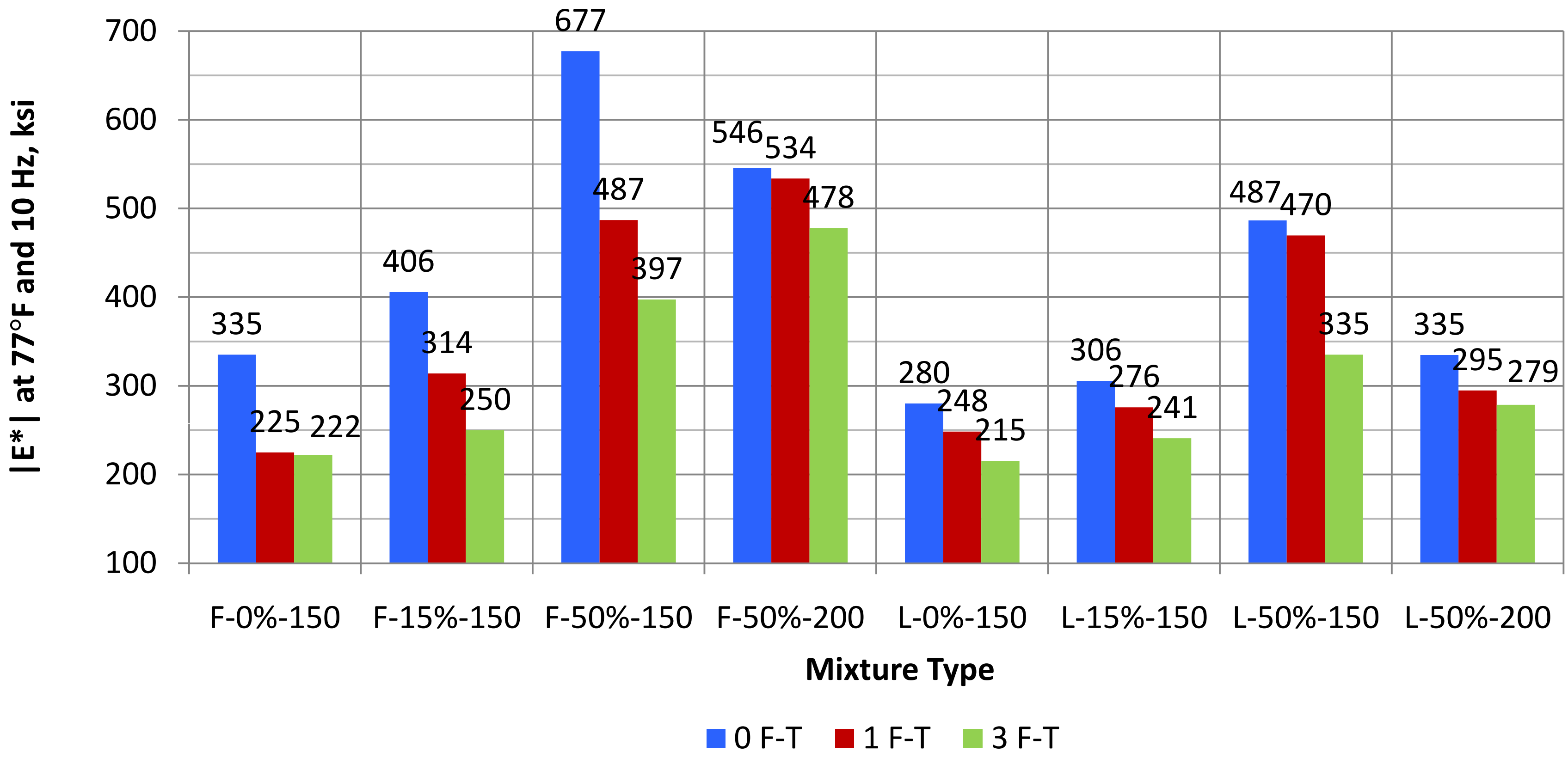
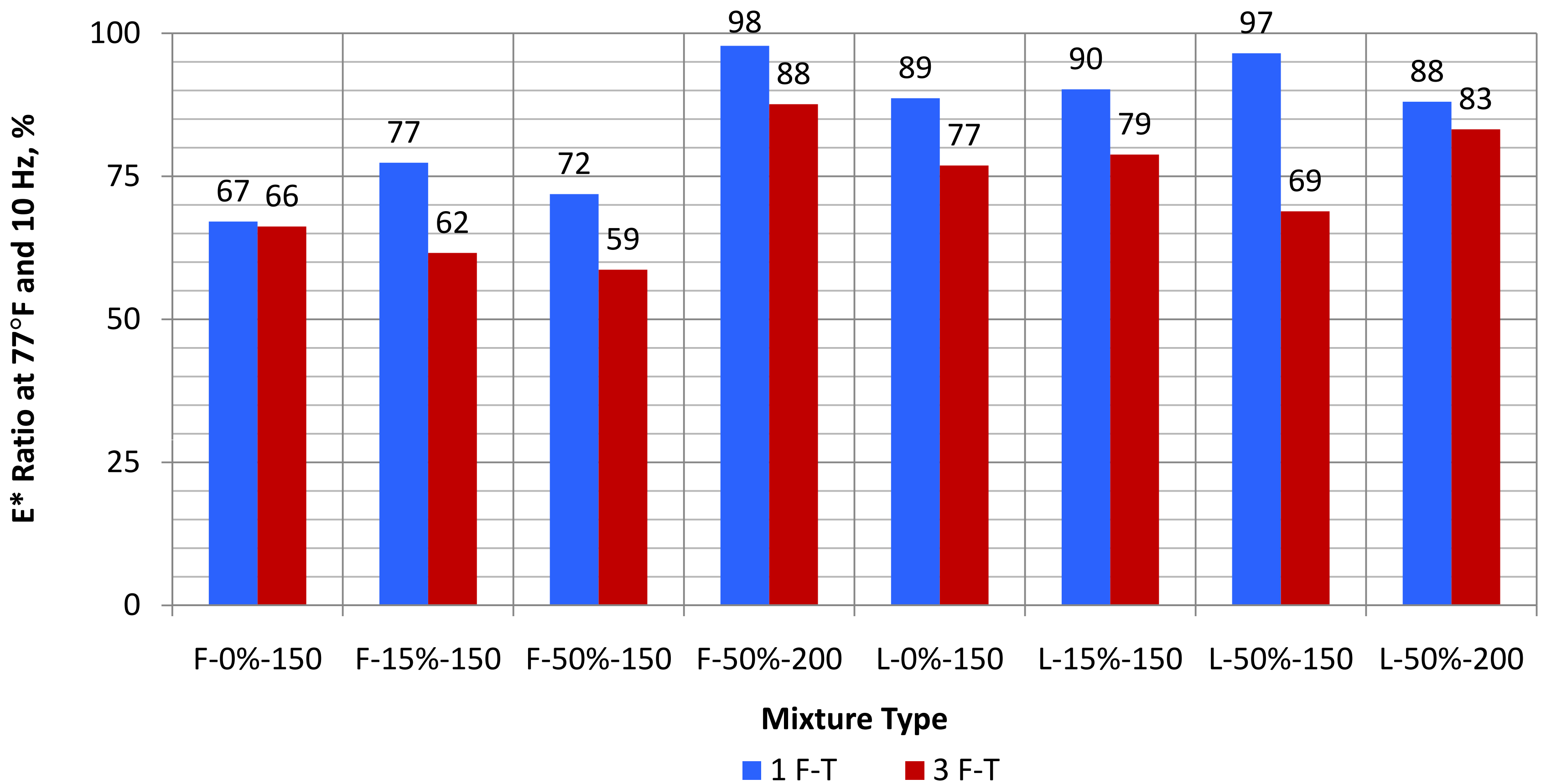


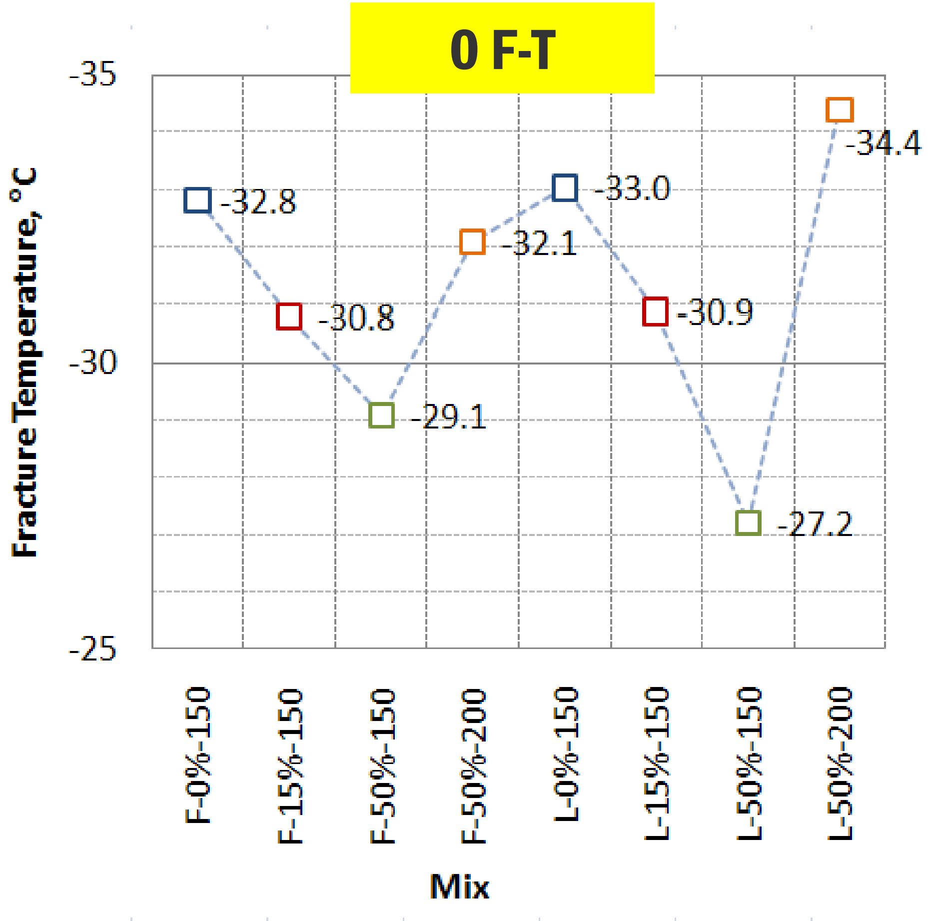
Resistance to Moisture Damage

E Ratio at 77°F*



Resistance to Thermal Cracking

TSRST Test Results – Fracture Temperature



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