Oxidative Aging of Asphalt Binders in Hot Mix Asphalt Mixtures

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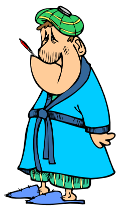
Introduction

- **Binder aging affects nearly all critical performance aspects of HMA pavements ← *important to quantify!***



- **Binders aged outside of mixtures have been frequently studied.**

- **Will binders aged in HMA mixtures have same engineering properties?**

Research Objective

- *Quantifying Oxidation of Asphalt Binders Aged in Compacted Mixtures*
    - Others have compared aging to binder viscosity or stiffness
    - Lack sufficient aging measurements of the binder
    - lack of previous studies specifically relating mixture properties to adequate aging measurements

Experimental Design

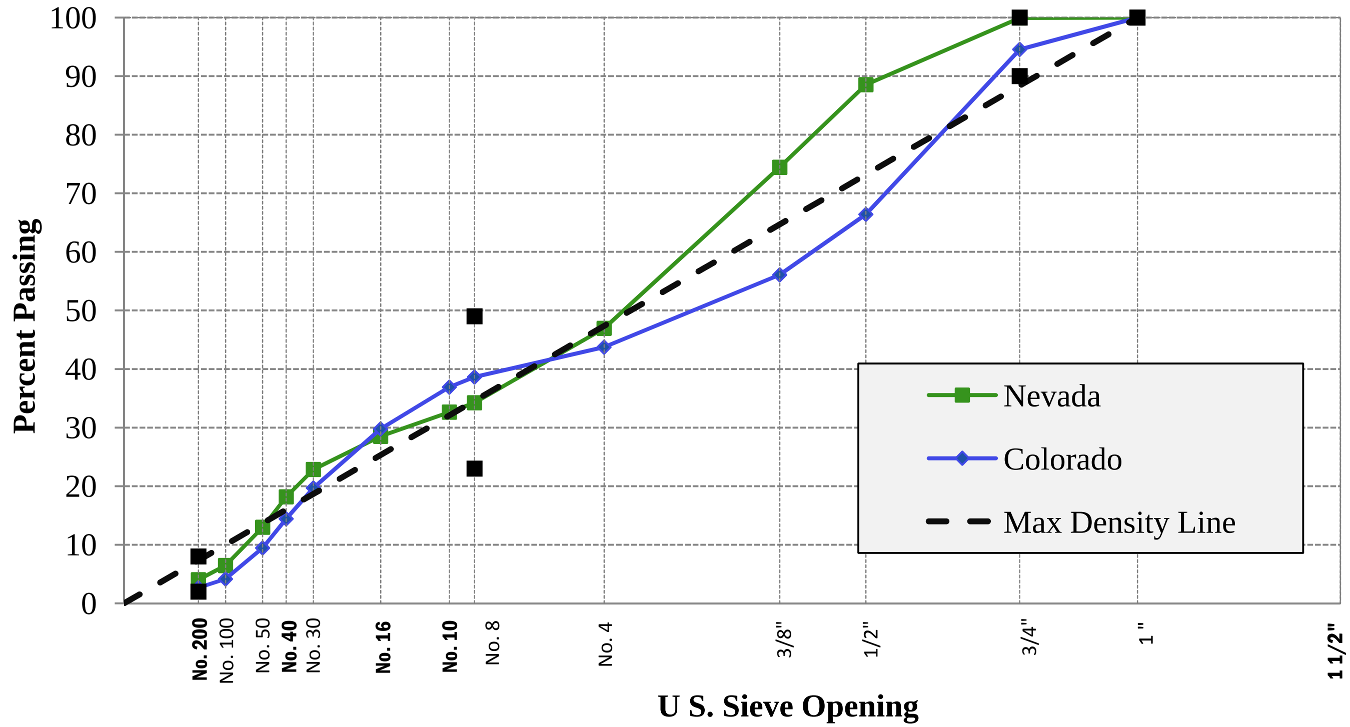
A. Aggregate sources: 2 (NV & CO)

B. Binders, single source: 2 (PG64-22 & PG64-28)

C. Mixture oven-aging levels: 4 (0, 3, 6 and 9 months at 140°F)

Experimental Design

A. Aggregate sources: NV & CO



Water Abs:

NV : 2.7%

CO: 0.9%

Experimental Design

B. Binders: single base stock and supplier (Paramount Petroleum Corp.)

- Neat PG64-22
- SBS Modified PG64-28

Experimental Design

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C. Agg. sources and binders combine to 4 different Superpave designed mixtures (6×10^6 ESALS)

Source ID	Source Location	Mineralogy	Agg. Water Abs. (%)	Binder Grade	Binder Content (% TWM)	App. Film Thickness (μm)
Nevada	Sparks	Rhyolite, Silica Sand	2.7	PG64-22	5.4	9
				PG64-28	5.2	9
Colorado	Morrison	Mica Gneiss, Mica Schist, Quartz Sand	0.9	PG64-22	4.5	11
				PG64-28	4.5	11

Experimental Design

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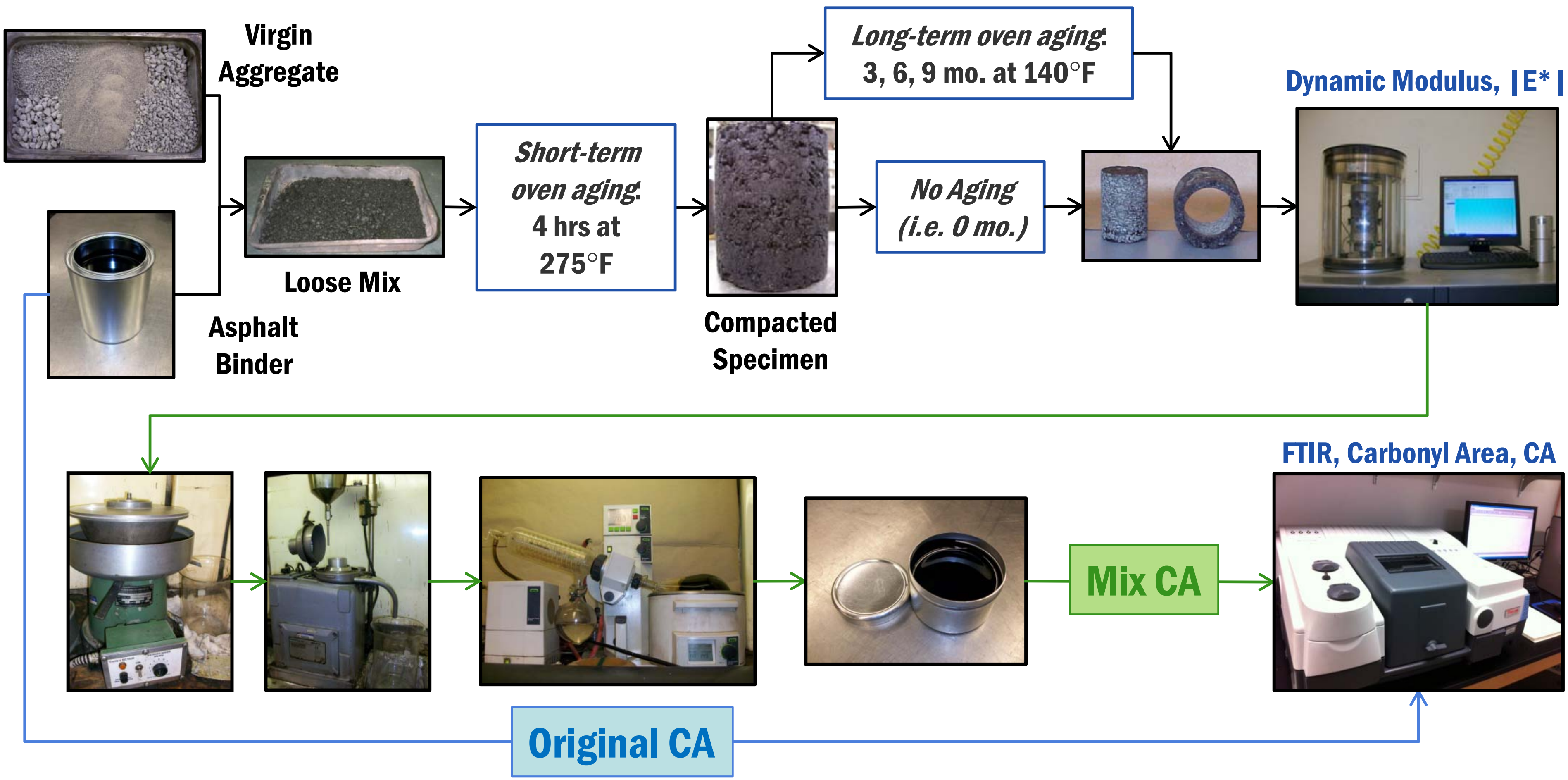
C. 4 Mixture oven-aging levels:

- 0, 3, 6, & 9 months at 140°F
- All samples short-term aged loose 4 hrs at 275°F
- SGC Compacted Specimens
- 7±0.5% Air Voids

Experimental Plan



Experimental Analysis

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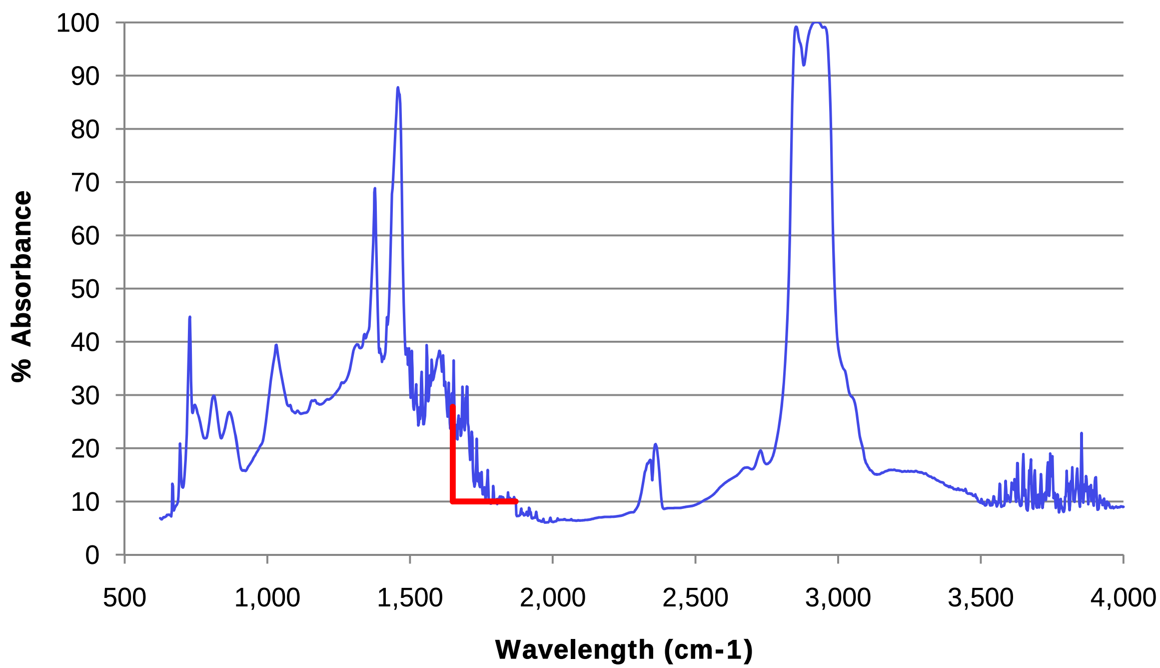
- CA vs Aging
- |E*| vs Aging
- |E*| vs CA

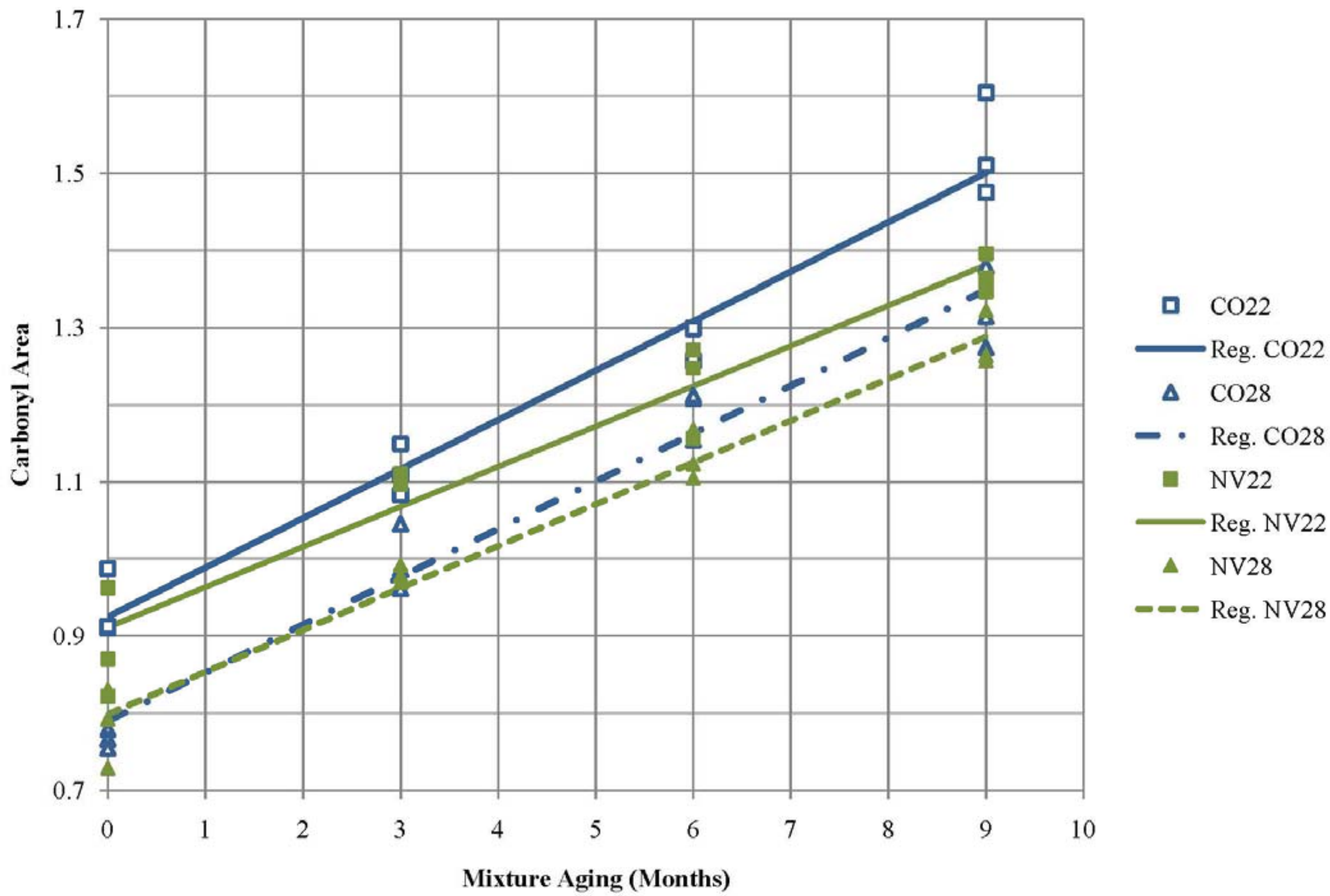
Results, Example

Carbonyl Area, CA (measurements are being done by Glover at A&M)



Wave numbers for the CA measurements between 1,650 and 1,870 cm^{-1}

Results, Carbonyl Area



Statistics, Carbonyl Area

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$$CA = \beta_0 + \beta_1(Age) + \beta_2(Mix) + \beta_3(Mix)(Age) \quad \text{[Eqn 1]}$$

- CA – measured Carbonyl Area;
- β_i – regression coefficients, i = 0,...,3;
- Age – months of oven aging at 140°F;
- Mix – categorical variable to differentiate the two mixtures being compared, value of 1 or 0 depending on which agg. and binder combination being considered.

Statistics, CA

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$$CA = [\beta_0+\beta_2(Mix)] + [\beta_1+\beta_3(Mix)] (Age)$$ [Eqn 1]

CA vs. Age	Comparison I		Comparison II		Comparison III		Comparison IV	
	CO22	NV22	CO28	NV28	CO22	CO28	NV22	NV28
Mix Variable	0	1	0	1	1	0	1	0

Statistics, CA Example

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$$CA = [\beta_0+\beta_2(Mix)] + [\beta_1+\beta_3(Mix)] (Age) \qquad \text{[Eqn 1]}$$

Comparison I

- Mix = 0, CO22 → $CA_{CO22} = [\beta_0] + [\beta_1] (Age)$
- Mix = 1, NV22 → $CA_{NV22} = [\beta_0+\beta_2] + [\beta_1+\beta_3](Age)$

Statistics, CA

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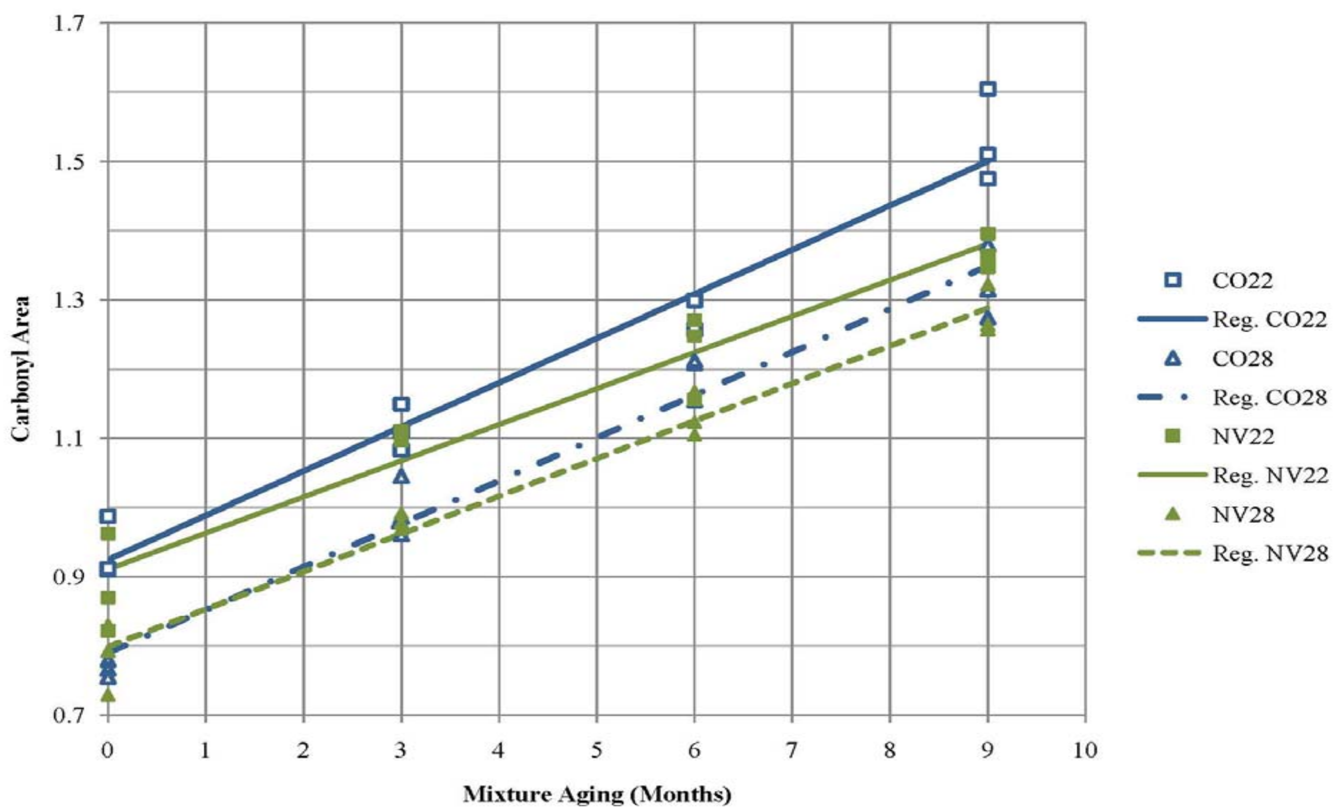
$$CA = [\beta_0+\beta_2(Mix)] + [\beta_1+\beta_3(Mix)]\ (Age)$$ [Eqn 1]

Mixes Compared	β_2	P-value	Sig.	β_3	P-value	Sig.
CO22 NV22	-0.0137	0.60				
CO28 NV28	0.0089	0.70				
CO22 CO28	0.1343	<0.00				
NV22 NV28	0.1122	<0.00				



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Findings, Carbonyl Area

1) CA increased linearly with Age;
2) Generally, CA was higher for PG64-22;
3) Within each binder, the intercepts were stat. the same;
   a) Aggregate source did not significantly affect short-term oxidation;
4) Oxidation rates were different between agg. sources;
   a) Agg. source, as it influences mix properties affected binder aging

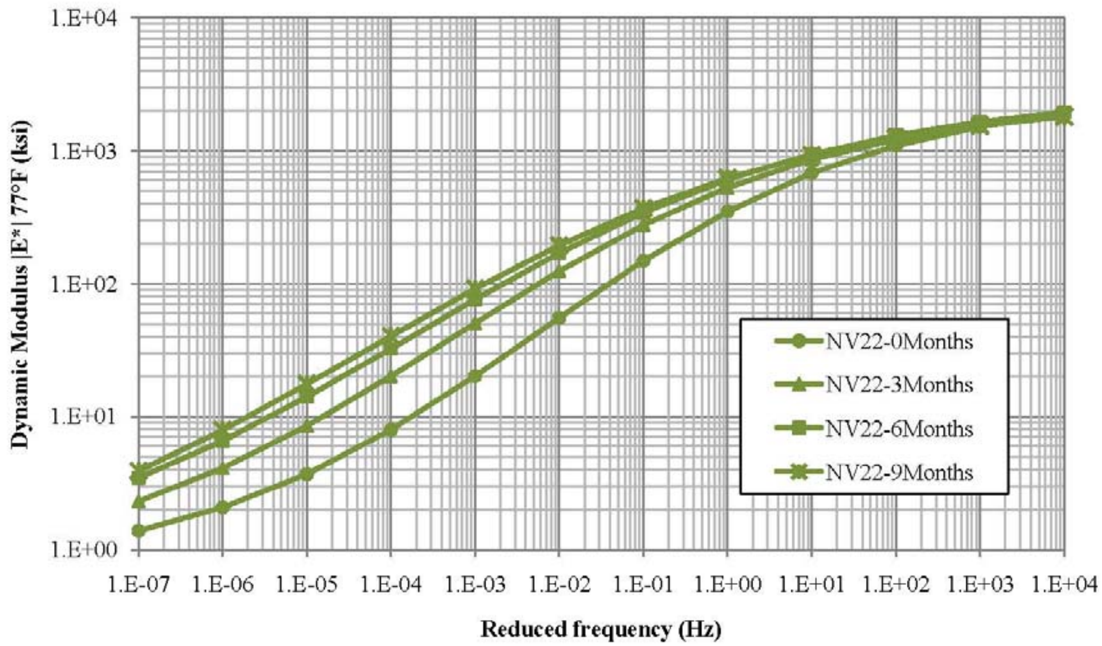
Findings, Carbonyl Area

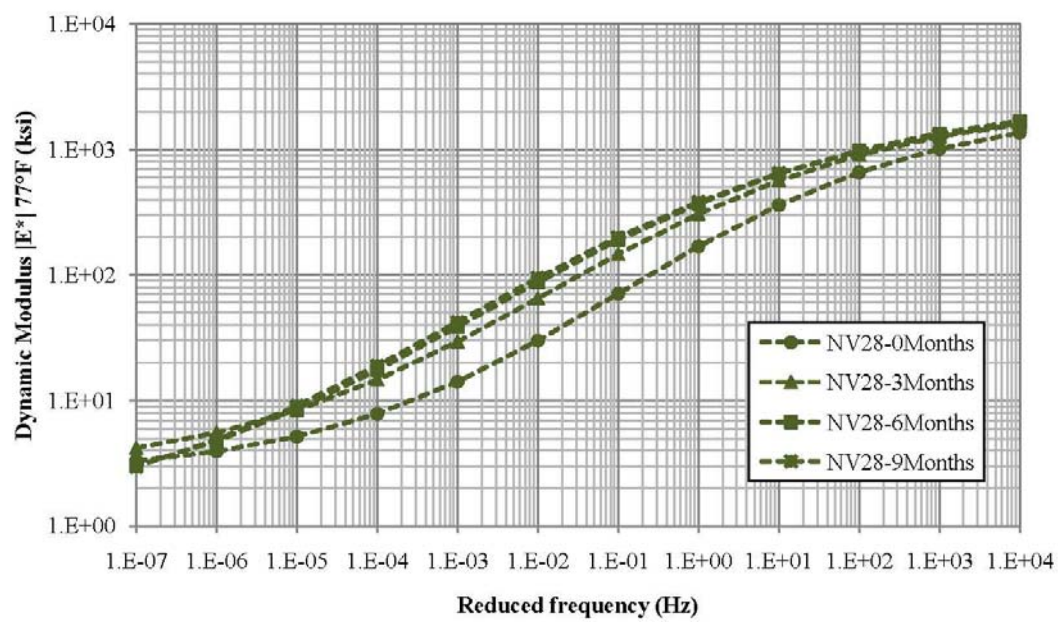
5) Within each agg., the intercepts were stat. different;
   a) Short-term aging of binders were not the same (original CA was the same)
   b) Polymer modification influences the Non-Linear Fast Rate Oxidation (short-term region)

6) Within each agg. source, after Fast Rate Oxidation, the binders aged at the same rate;
   a) Binders from same base stock (similar oxidation characteristics)
   b) Indicating Mix Characteristics Influence the rate of binder oxidation

Results, |E*|

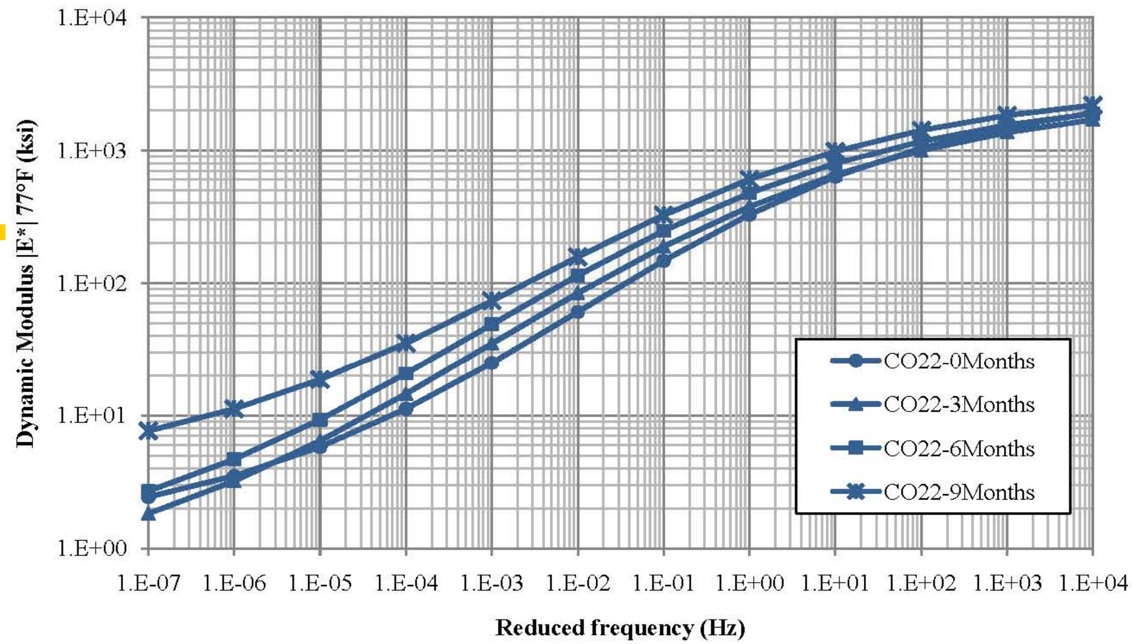
Nevada Mixes

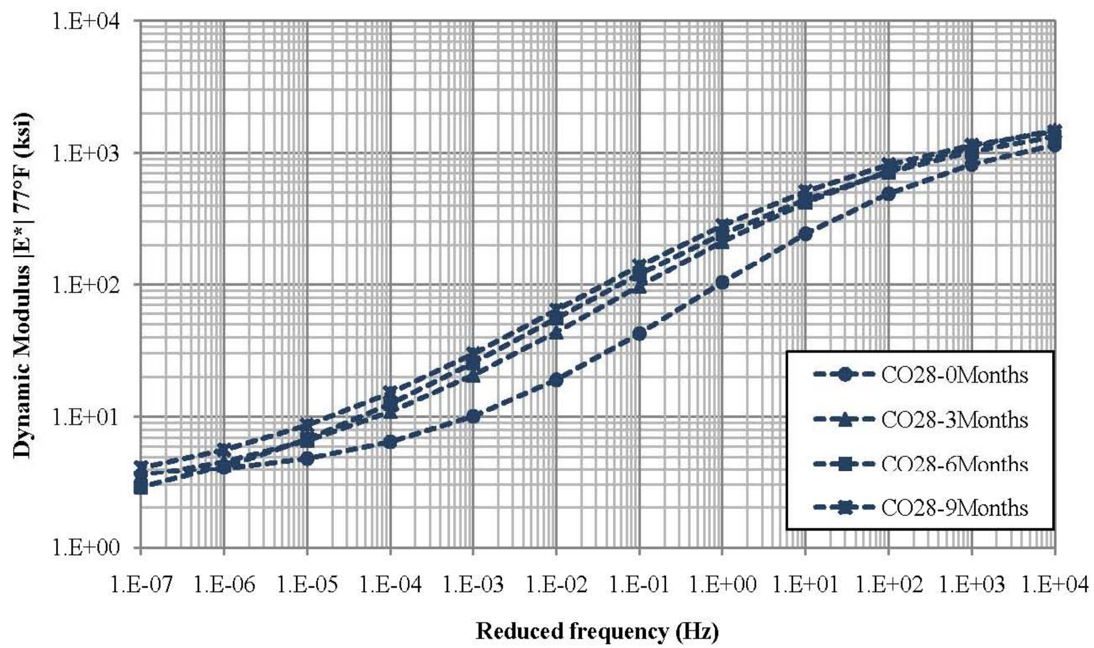




Results, |E*|

Colorado Mixes





Statistics, |E*| vs. CA

$$|E^*| = \beta_4 + \beta_5(CA) + \beta_6(Mix) + \beta_7(Mix)(CA) \quad \text{[Eqn 2]}$$

- $|E^*|$ – measured Dynamic Modulus, 0.1Hz;
- β_j – regression coefficients, j = 4,...,7;
- CA – measured Carbonyl Area;
- Mix – categorical variable to differentiate the two mixtures being compared, value of 1 or 0 depending on which agg. and binder combination being considered.

Statistics, |E*| vs. CA

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$$|E^*| = [\beta_4 + \beta_6(Mix)] + [\beta_5 + \beta_7(Mix)]\,(CA) \qquad \text{[Eqn 2]}$$

70 and 100°F	Comparison I		Comparison II		Comparison III		Comparison IV	
	CO22	NV22	CO28	NV28	CO22	CO28	NV22	NV28
Mix Variable	0	1	0	1	1	0	1	0

- Analysis conducted for both 70 and 100°F

Statistics, |E*| Example

$$|E^*| = [\beta_4+\beta_6(Mix)] + [\beta_5+\beta_7(Mix)]\,(CA)$$ [Eqn 2]

Comparison I at 70°F

- Mix = 0, CO22 → $|E^*|_{70\text{-}CO22} = [\beta_4] + [\beta_5(CA)]$
- Mix = 1, NV22 → $|E^*|_{70\text{-}NV22} = [\beta_4+\beta_6] + [\beta_5+\beta_7](CA)$
- Same model form for both 70°F and 100°F

Statistics, |E*|, 70°F

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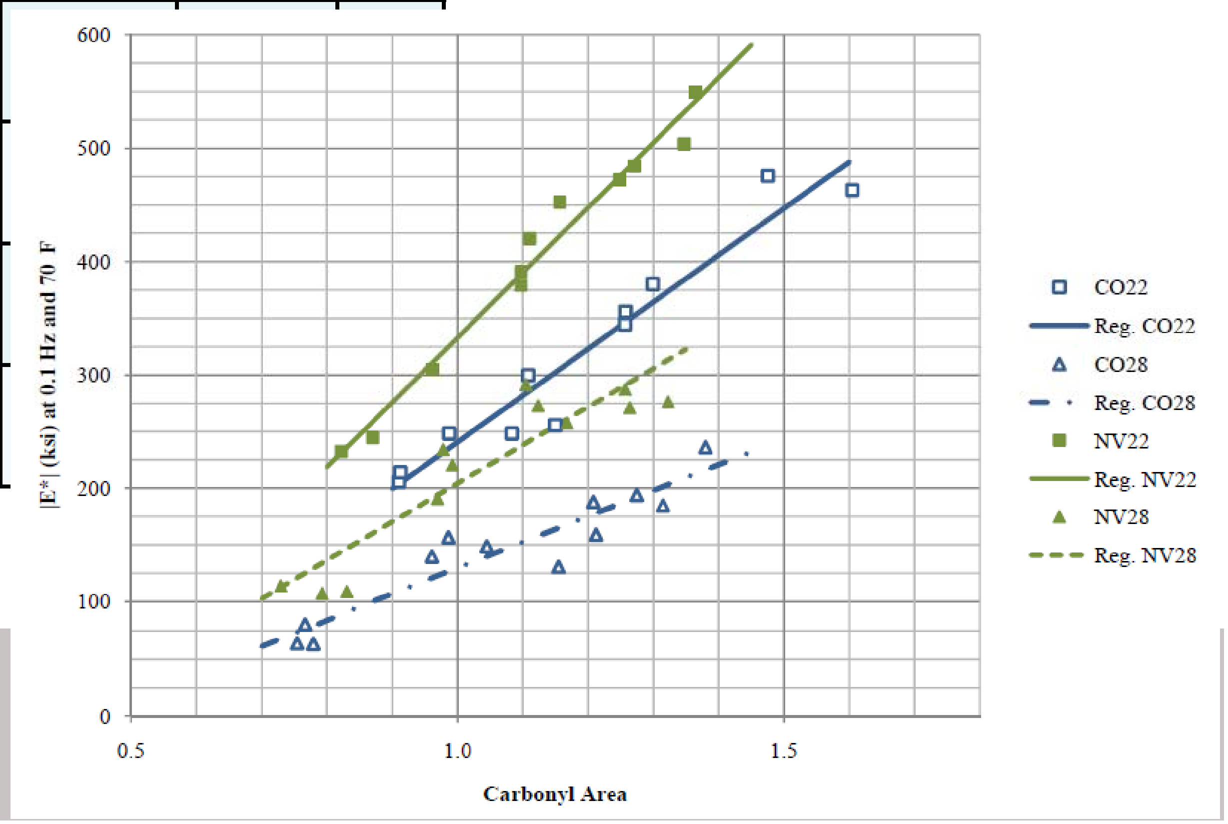
$$|E^*|_{70} = [\beta_4+\beta_6(Mix)] + [\beta_5+\beta_7(Mix)](CA)$$ **[Eqn 2.a]**

Mixes Compared	β_6	P-value	Sig.	β_7	P-value	Sig.
CO22 NV22	-67.58	0.255	NS			
CO28 NV28	-36.43	0.530	NS			
CO22 CO28	-73.79	0.173	NS			
NV22 NV28	-104.94	0.119	NS			



Findings, |E*|, 70°F

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7) Within each binder, the intercepts were stat. the same;
   a) Agrees with CA vs Age analysis, Item 3.a

8) Within each binder, Rates of |E*| increase lower for CO;
   a) Rate of |E*| increase dependent upon mixture characteristics;

9) Within each agg., rate of |E*| increase lower for PG64-28;
   a) Supports that different binders influence the binder aging, particularly polymer modification

Statistics, |E*|, 100°F

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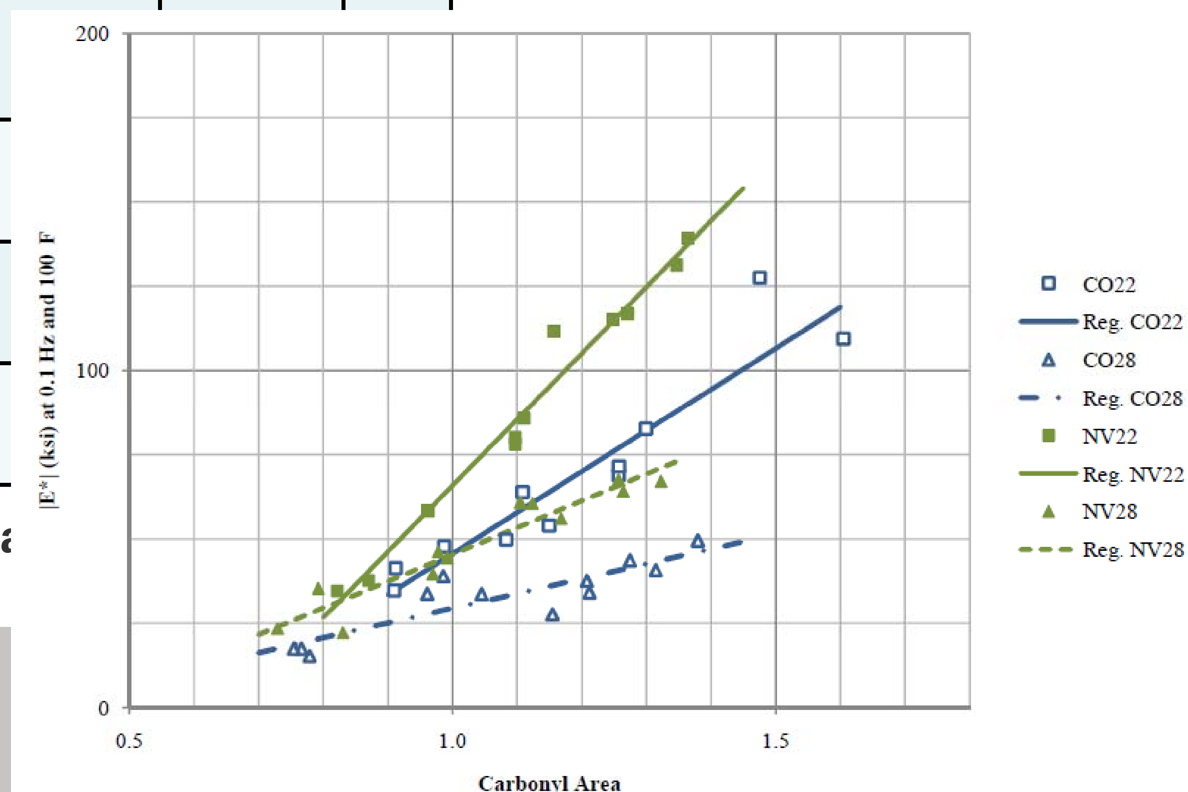
$$|E^*|_{100} = [\beta_4+\beta_6(Mix)] + [\beta_5+\beta_7(Mix)](CA)$$ [Eqn 2.b]

Mixes Compared	β_6[1]	P-value[1]	Sig.	β_7[1]	P-value[1]	Sig.
CO22 NV22	-54.21	0.027	SL[1]			
CO28 NV28	-19.51	0.110	NS			
CO22 CO28	-61.35	0.004	SL[1]			
NV22 NV28	-96.05	<0.001	SL[1]			

1 – Change in result as compa



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Findings, |E*|, 100°F

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10) Within each binder, Rates of |E*| increase lower for CO;

   a) Rate of |E*| increase dependent upon mixture characteristics;

11) Within each agg., the intercepts of the PG64-22 mixtures were sig. lower than the PG64-28

   a) Supports that different binders influence the binder aging, Item 9)

12) Within each agg., the rate of |E*| increase is higher with PG64-22;

   a) Supports that different binders influence the binder aging, particularly polymer modification

Conclusions

- Carbonyl indicates:
  - mix properties *did not affect short-term aging in loose condition*, but the binder properties do play a roll
  - mix properties *did affect long-term aging in compacted mixes*, but the binder did age at nearly the same rate with respect to time

Conclusions, cont'd

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- Mixture stiffness, |E*|, indicates:
  - mix properties *may affect short-term aging in loose condition* (depending on analysis temperature)
  - mix properties *did affect long-term aging in compacted mixes*

Conclusions, cont'd

- |E*| vs. CA indicates significantly different aging characteristics between the two binder grades

- Both the binder and the mix characteristics influence the aging of asphalt binders in mixtures.

Further/On-Going Research

- Further consideration of
  - influence of agg. properties on binder aging (Abs.)
  - mix characteristics (AV [total vs. accessible], AFT, $P_{b\text{-}eff}$ vs. $P_{b\text{-}total}$, etc.)
- Evaluate ext./rec. binder properties (G*, ZSV, SENB, etc.)
- Evaluate low temperature properties of aged mixes:
  - fracture temperature and stress (TSRST)

Acknowledgments

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Thank You