Hydrolytically Stable Silane Additives for Improving the Performance of Waterborne Acrylic Roof Coatings

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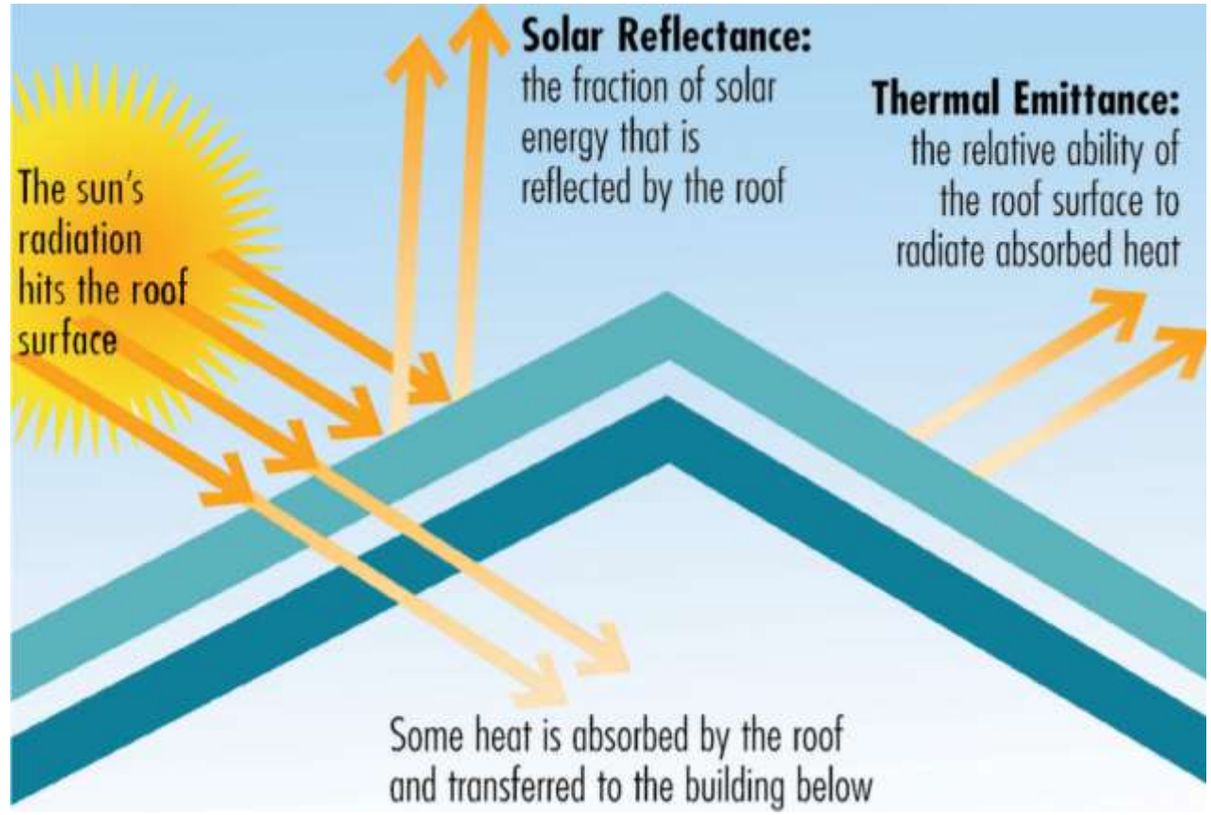
The Importance & Requirements of Cool Roofing

- Reduce ambient and indoor air temperatures
- Climate change mitigation
- Reduce heat island effect
- Energy savings
- Long-term trend toward reflective roofing

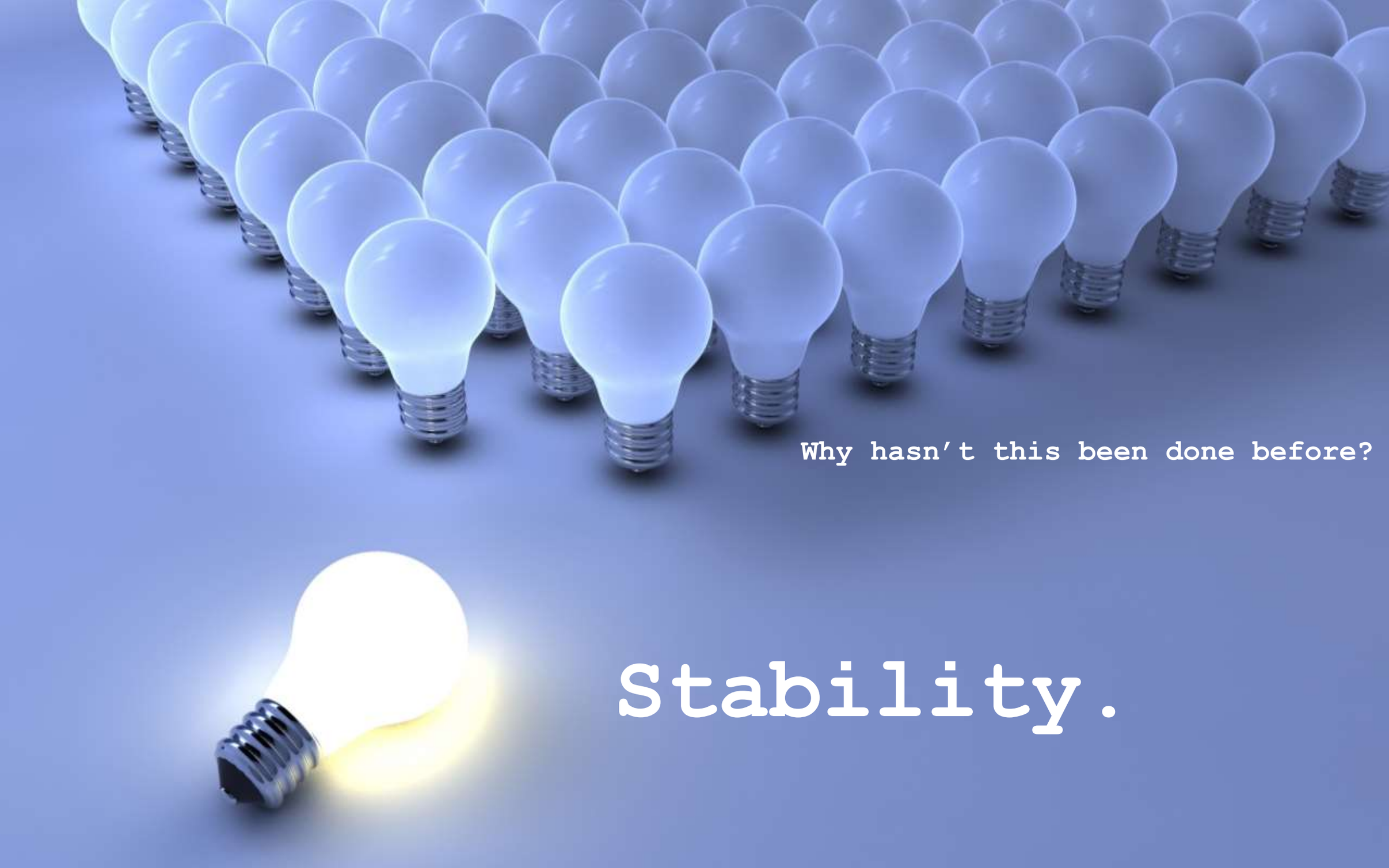


Requirements

- ASTM D6083 I & II
- Water resistance
- Solar reflectance
- Stain resistance
- Elongation and toughness

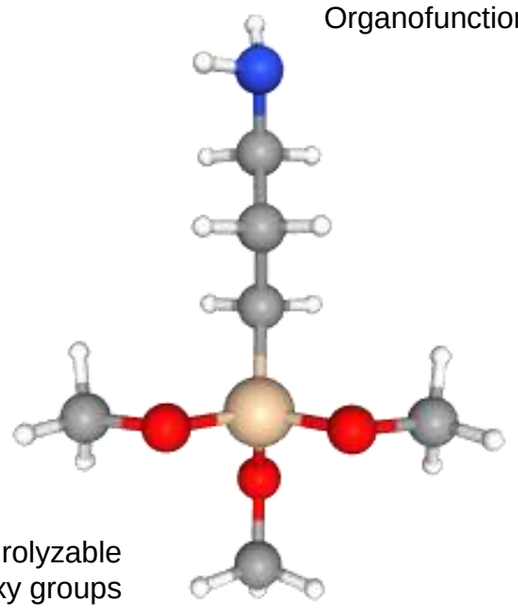
Effects of Silanes in Roof Coatings

- Ponding water resistance
  - Reduce water uptake by 40-70%
  - Improve wet adhesion up to 40-150+%
- Primerless dry adhesion
  - Up to 40% improvement on difficult substrates
- Improved stain resistance
- Weatherability & durability


Why hasn't this been done before?
Stability.

Stability of Silanes in Aqueous Dispersions

Silane Structure



- Hydrolyzable alkoxy groups on silanes are water reactive
  - Traditional silanes are shelf-stable in aqueous dispersion for only days/weeks
  - Unstable silanes cause viscosity increase and gelling
- Increasing hydrolytic stability of alkoxy group increases shelf stability

methoxy < ethoxy < dialkoxy < oligomeric

Increasing hydrolytic stability

- Silanes must be reactive enough to improve the final coating

Comprehensive Study of Silanes in Waterborne Acrylic Roof Coatings

- **Elastomeric roof coatings formulas based on**
  - Waterborne Acrylic Resin
- **Two silanes ultimately selected for their stability in water**
  - Amine-functional silane monomer
  - Epoxy-functional silane oligomer
- **Performance testing**
  - Stability (viscosity v. time at 45C)
  - Water resistance (ASTM D471, 7 day immersion)
  - Dry & wet adhesion (ASTM C794, 7 day immersion)
  - Stain resistance (ASTM D3719, carbon black, iron oxide slurry)
  - Physical properties, initial and aged (ASTM D2370, 1000h QUV)
- **Substrates (aged):**
  - PVC*, EPDM*, Asphalt^

* Weathered in QUV for 350 hours
^ Weathered outdoors for 3 months

Stability

Adhesion

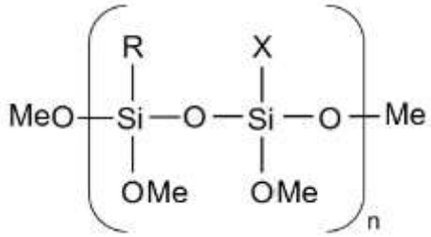
Elongation

Water Resistance

Stain Resistance

Meet the Candidates

Epoxy-functional Silane Oligomer



R = X = glycidoxypropyl

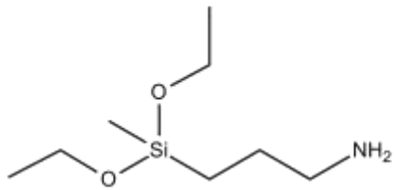
Properties

Molecular weight	g/mol	> 2000
Viscosity (25 °C)	mPa·s	700 - 1200
Flash point	°C	> 93

Epoxy-functional Silane Oligomer

- Oligomeric, low-monomer epoxy silane
- Colorless and non-yellowing
- 258 – 320 g/L VOC (methanol)
- No hazard label
- TSCA listed

Amine-functional Silane Monomer



Properties

Molecular weight	g/mol	191
Viscosity (25 °C)	mPa·s	2
Flash point	°C	88

Amine-functional Silane Monomer

- Monomeric, amine functional
- Dialkoxysilane
- Colorless to yellow
- 443 g/L VOC (ethanol)
- Corrosive hazard label
- TSCA listed

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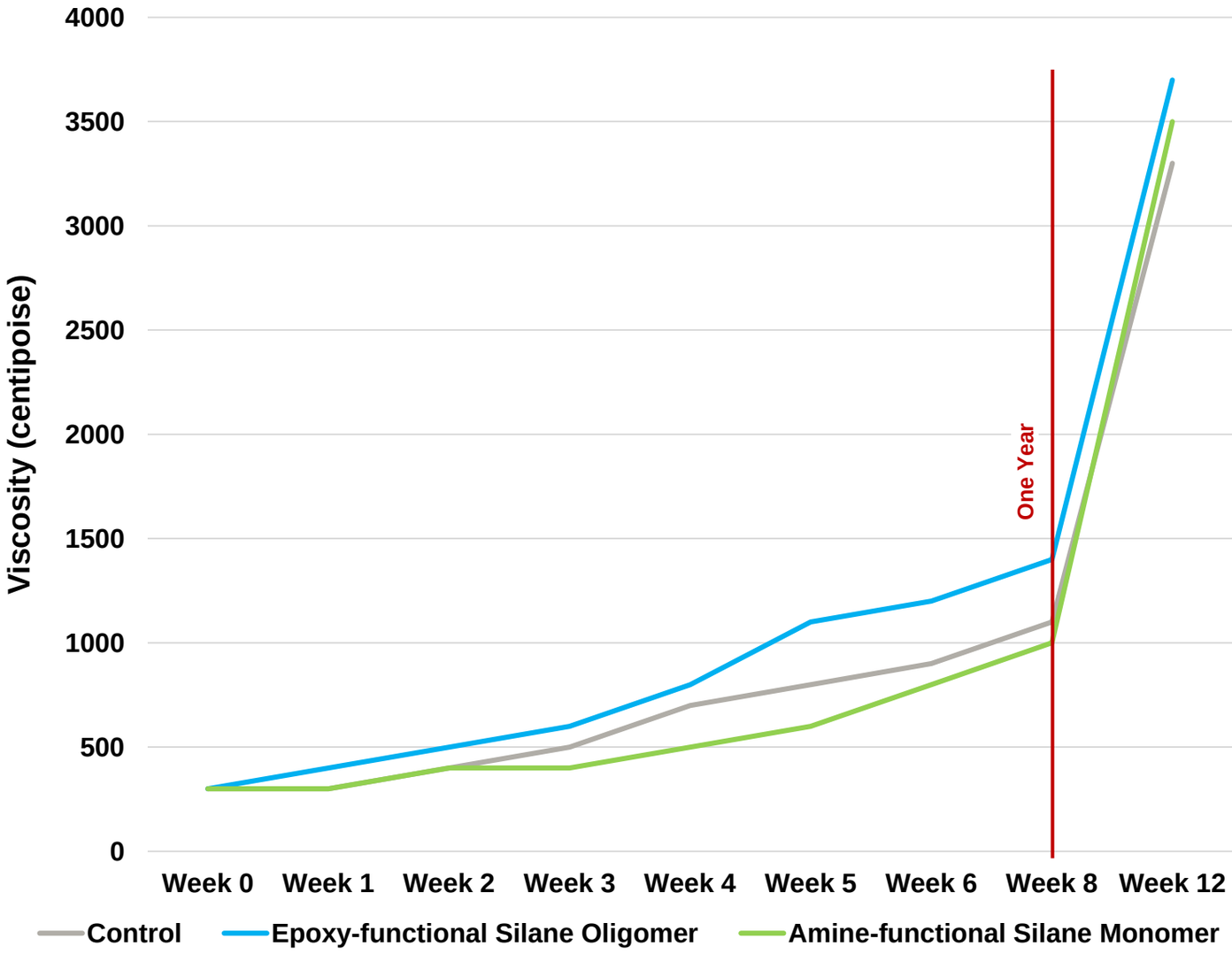
Waterborne Acrylic Roof Coating Formulation

Material	Supplier	Quantity (wt%)
Grind		
DI H_2O	-	12.51
Dispersant	BASF	0.40
Dispersant	ICL Phosphate Specialty	0.12
Calcium Carbonate	Huber Engineered Materials	34.95
Titanium Dioxide	Chemours	5.83
Zinc Oxide	Sigma Aldrich	3.88
Letdown (after 24h sitting)		
Waterborne Acrylic Resin	DOW	38.95
Coalescent	Eastman	0.58
Biocide	DOW	0.17
Aqueous Ammonia	Sigma Aldrich	0.08
Propylene Glycol	Sigma Aldrich	2.02
Thickener	Ashland	0.35
	Total	**100.00**

Procedure

1. Add DI Water to container under low speed
2. Add dispersants to container under low speed
3. Under low speed, add Calcium Carbonate, Titanium Dioxide, and Zinc Oxide to container
4. Mix at high speed in dispermat for 15 – 30 minutes
5. Return to low mixing speed
6. Add Waterborne Acrylic Resin under low speed
7. Add coalescent under low speed
8. Add biocide under low speed
9. Premix Propylene Glycol and thickener out of container
10. Add Aqueous Ammonia under low speed
11. Immediately add Propylene Glycol + thickener to container and mix under low speed
12. **Post-add 0.22% silane (1% on resin solids)**

Stability – Silanes in Waterborne Acrylic Resin

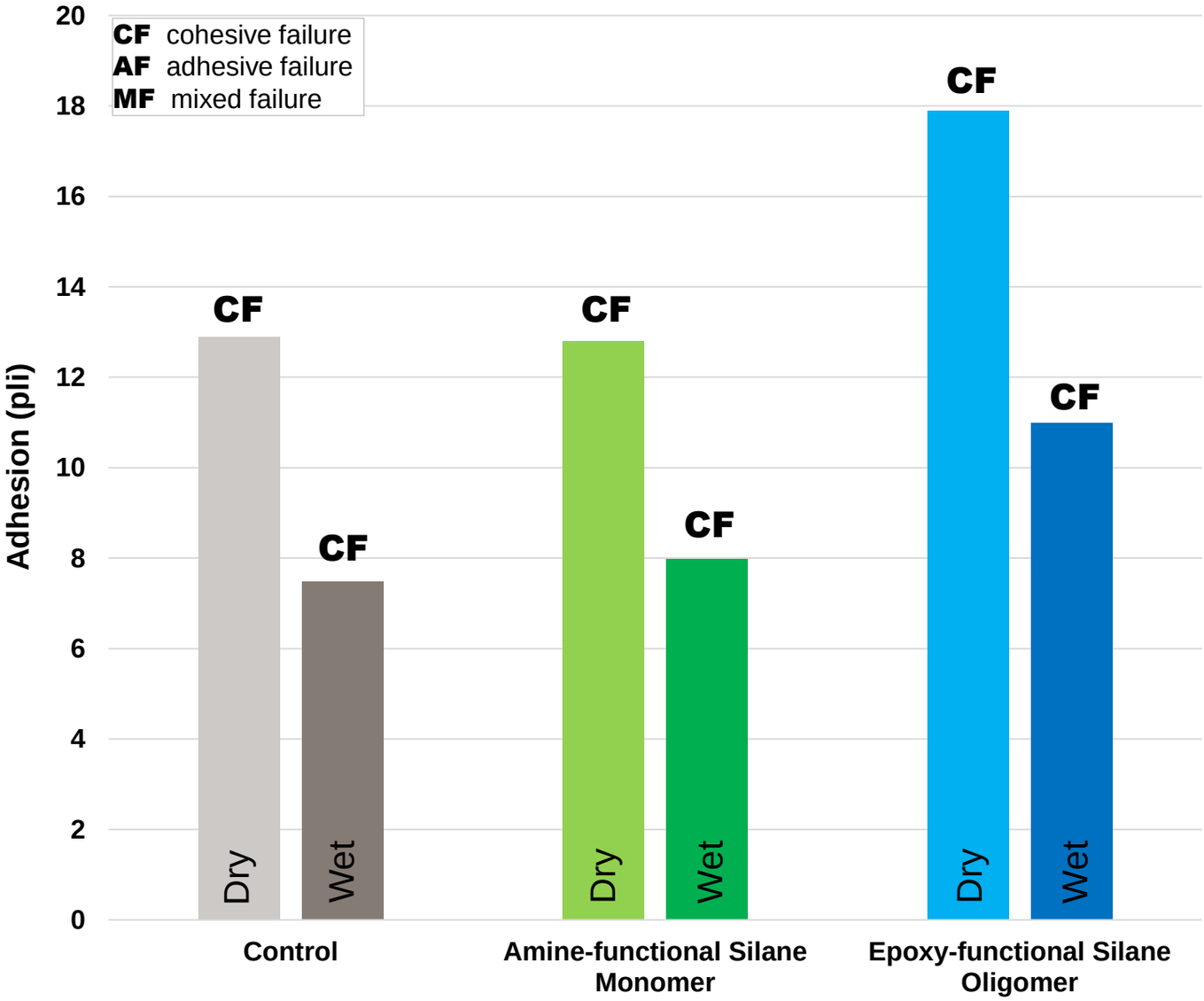


- 45C oven, 8 weeks = 12 months at room temp.
- Both silanes relatively stable compared to control
- Unstable silanes (not shown) gelled in 2-4 weeks

Water Resistance - Silanes in Waterborne Acrylic Roof Coating

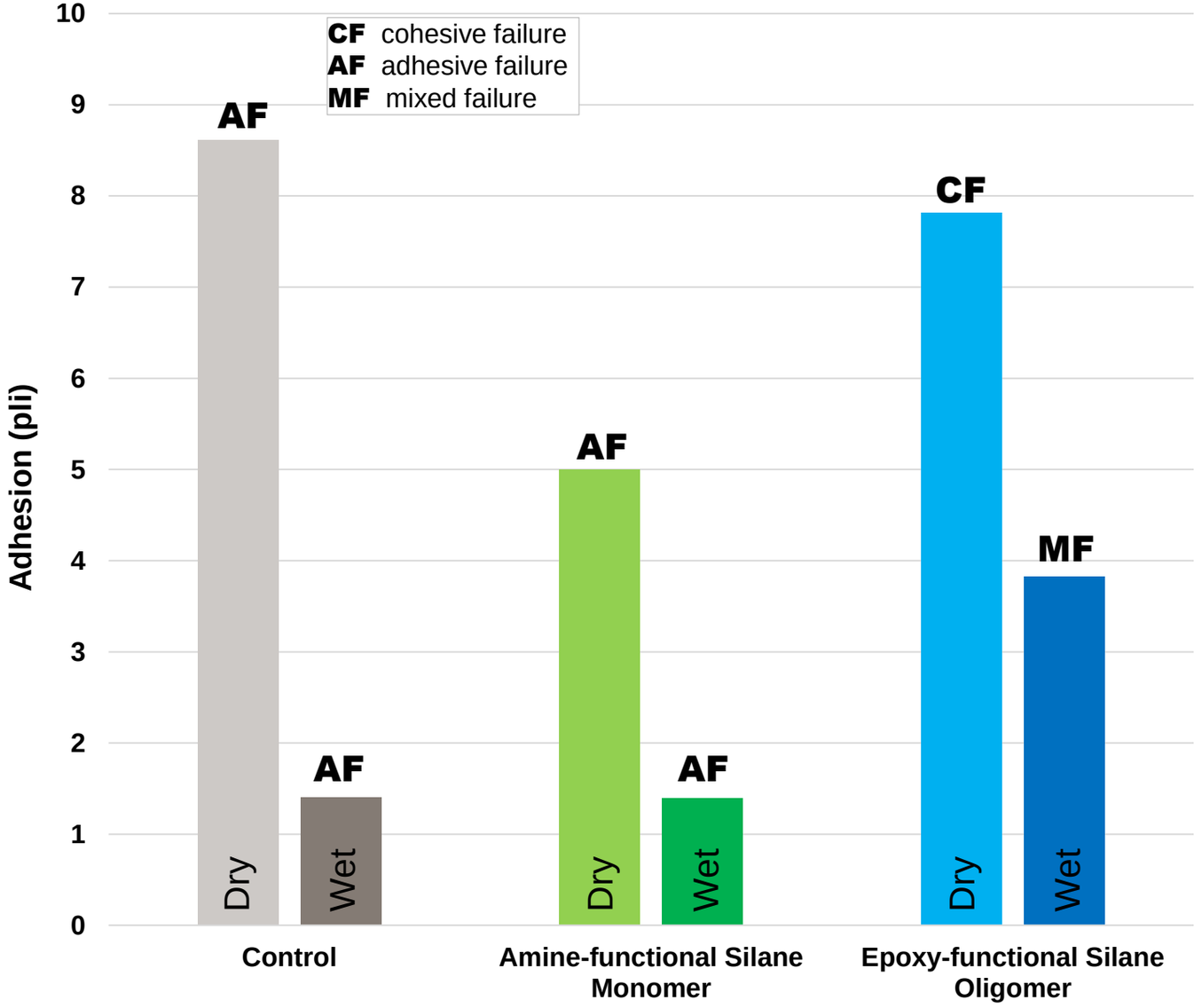
- ASTM D471 (on aluminum), 7 day immersion
- Epoxy-functional Silane Oligomer reduced water uptake by **>60%**
- Epoxy-functional Silane Oligomer prevented delamination and blistering
- Amine-functional Silane Monomer reduced water uptake by 40% but still delaminated
- Control gained considerable weight, blistered

Dry and Wet Adhesion to PVC – Silanes in Waterborne Acrylic Roof Coating

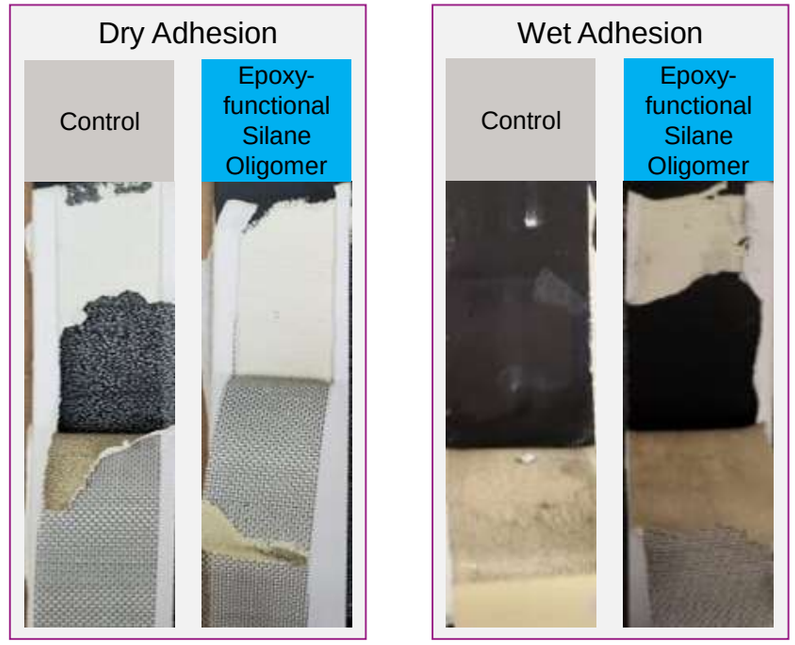


- Epoxy-functional Silane Oligomer increased dry and wet adhesion to PVC by **40-45%**
- Amine-functional Silane Monomer did not increase adhesion to PVC

Dry and Wet Adhesion to EPDM – Silanes in Waterborne Acrylic Roof Coating



- Epoxy-functional Silane Oligomer improved wet adhesion to EPDM by **>150%**
- Control lost over 80% of adhesion to EPDM when exposed to water
- Amine-functional Silane Monomer reduced dry adhesion and had no effect on wet adhesion



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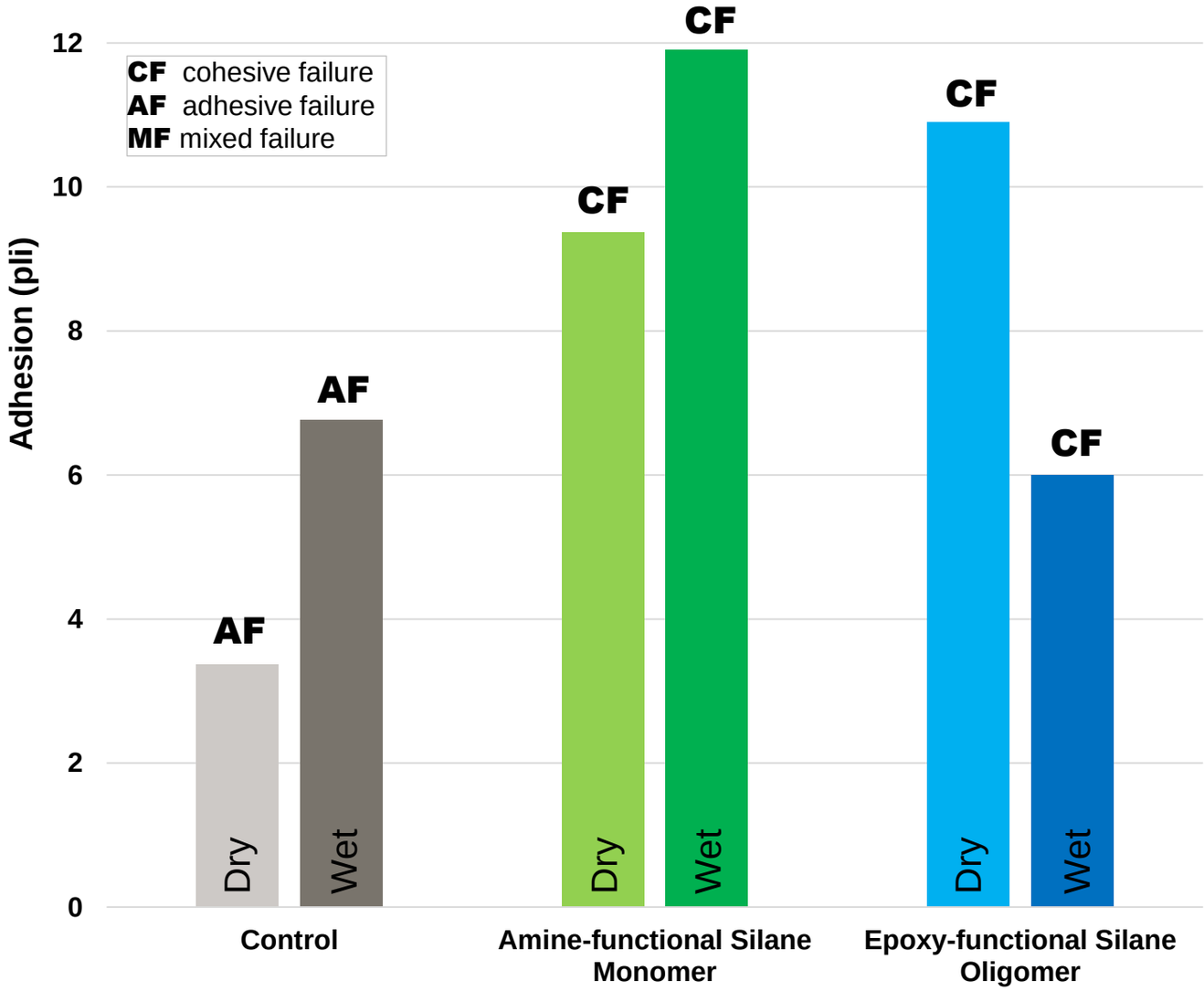
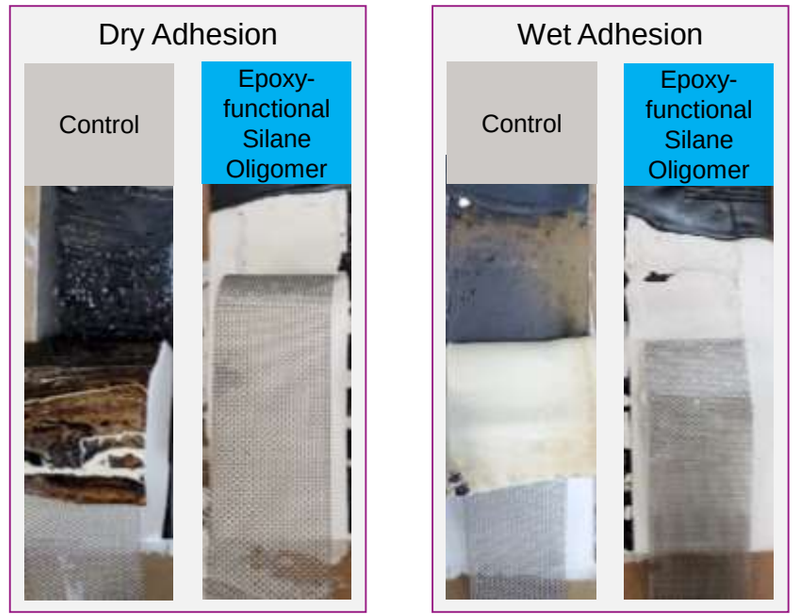
Dry and Wet Adhesion to Asphalt – Silanes in Waterborne Acrylic Roof Coating



- Epoxy-functional Silane Oligomer and Amine-functional Silane Monomer resulted in cohesion failure compared to control adhesion failure
- Amine-functional Silane Monomer improved dry and wet adhesion to asphalt by >130%



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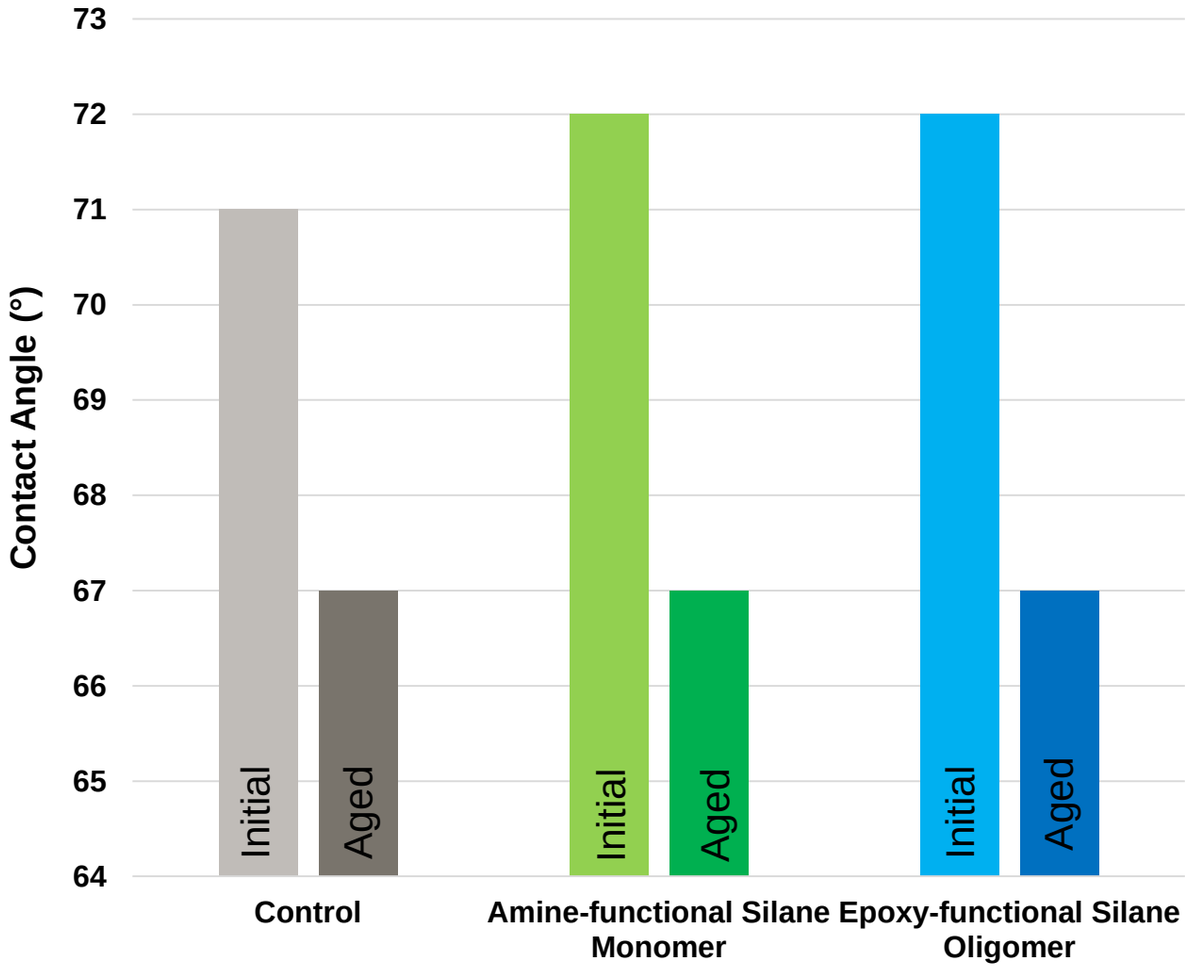
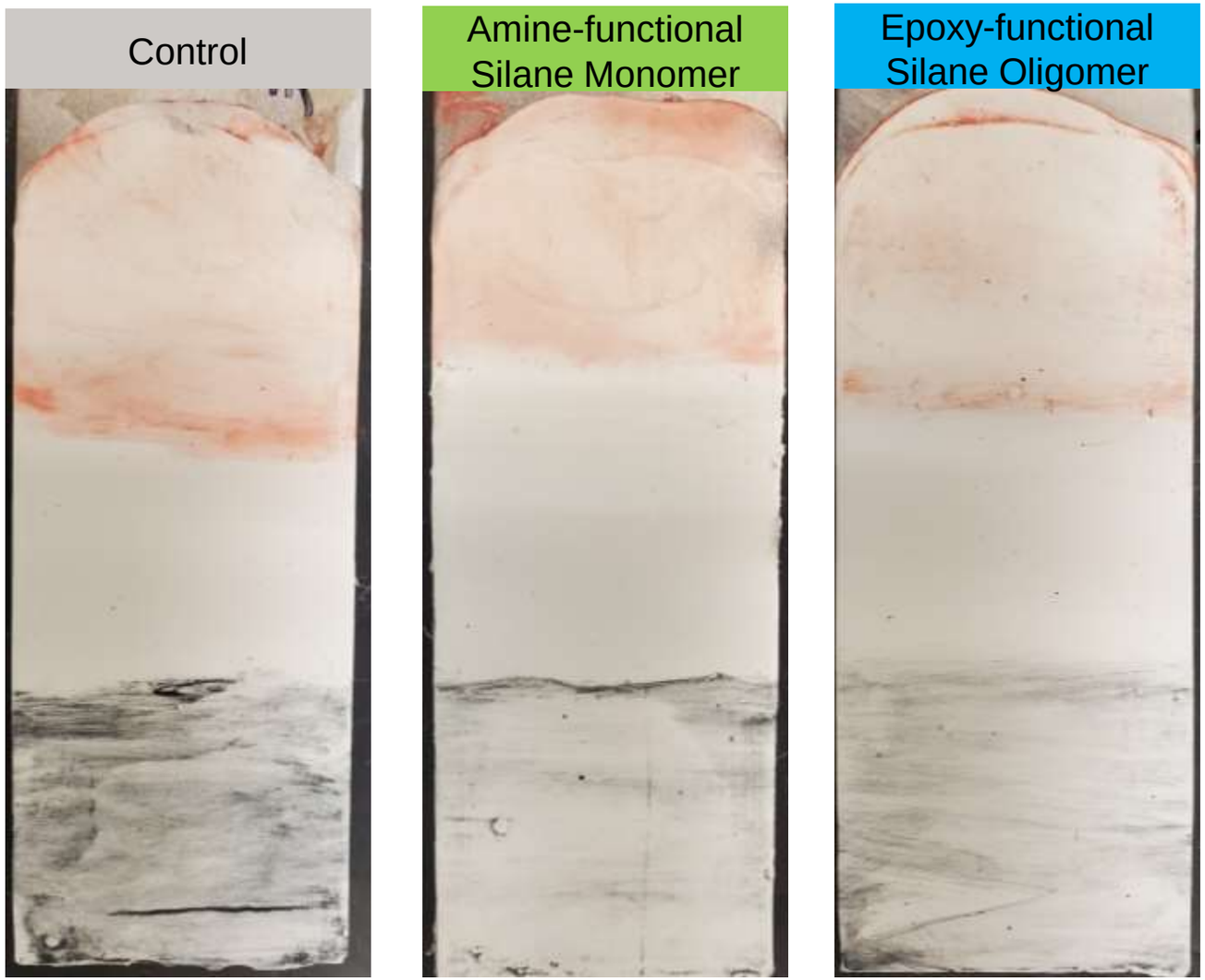
Contact Angle – Silanes in Waterborne Acrylic Roof Coating



- 1000h QUV
- Silanes have minimal effect on surface contact angle in waterborne acrylic roof coating

Stain Resistance – Silanes in Waterborne Acrylic Roof Coating

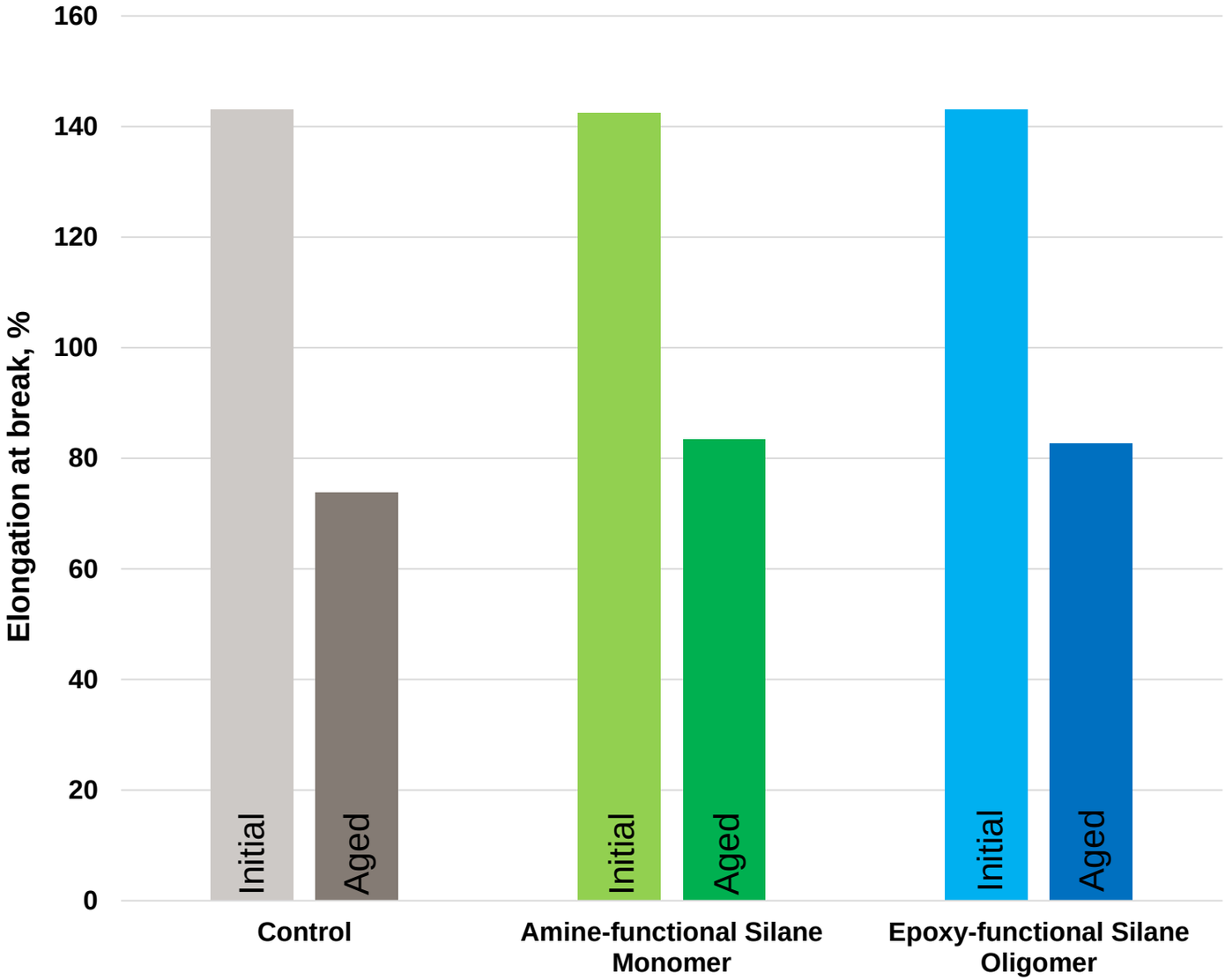


- Epoxy-functional Silane Oligomer and Amine-functional Silane Monomer both resisted staining more than coating made without silane

Red Iron Oxide

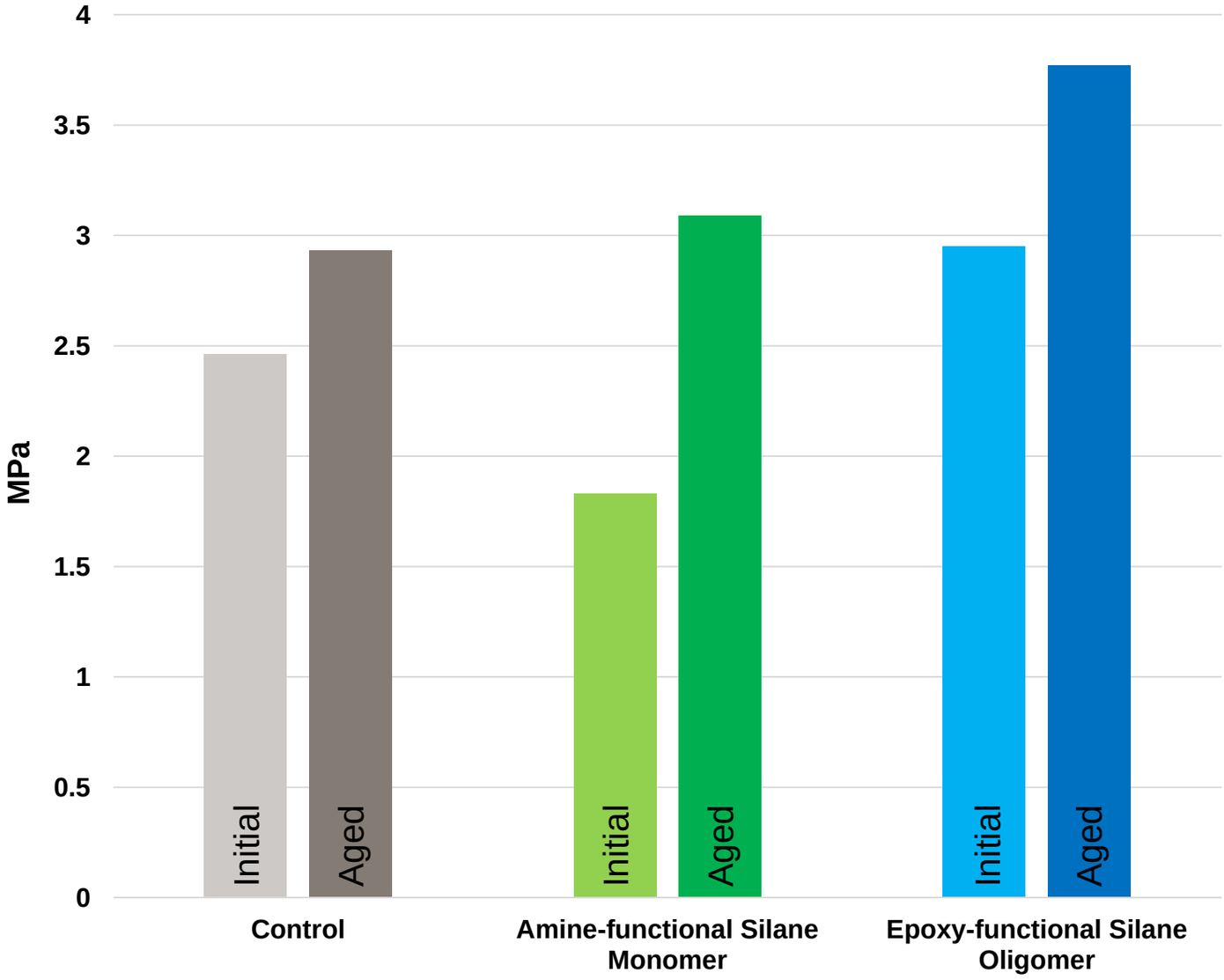
Carbon Black

Elongation – Silanes in Waterborne Acrylic Roof Coating



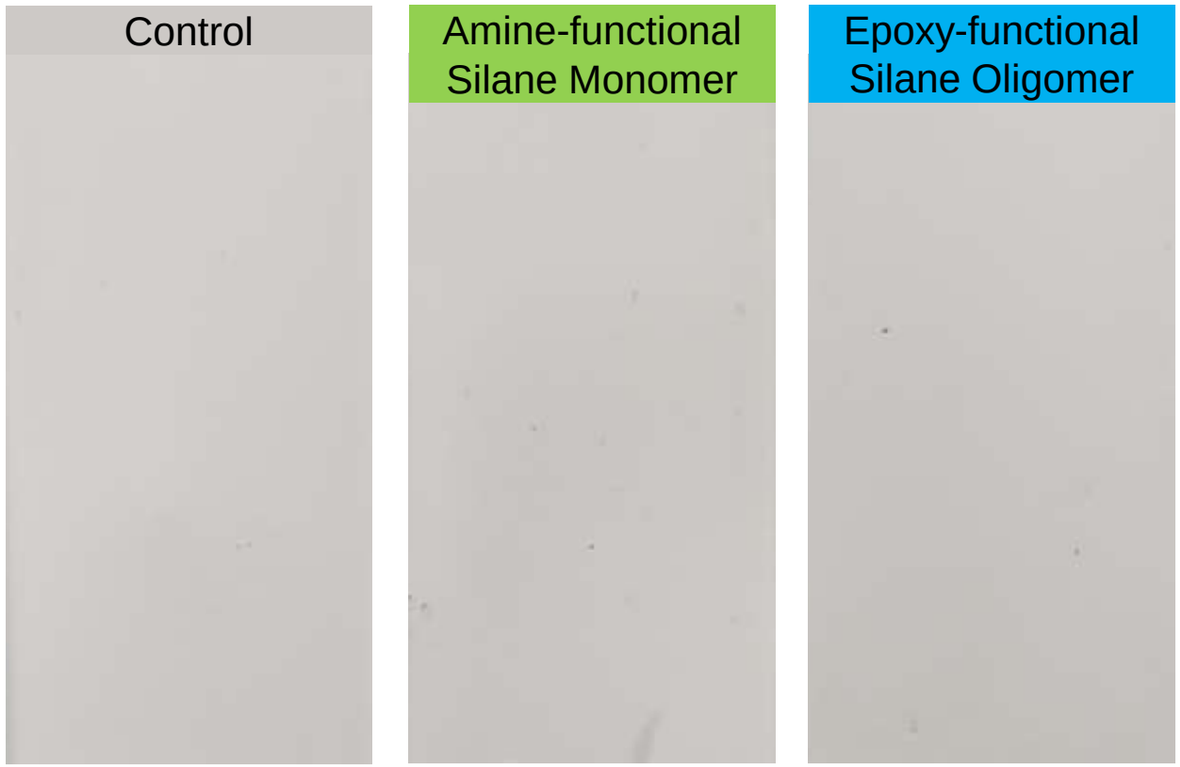
- 1000h QUV
- Silane did not affect initial elongation
- Coatings with Amine-functional Silane Monomer & Epoxy-functional Silane Oligomer retained more elongation after aging

Tensile Strength – Silanes in Waterborne Acrylic Roof Coating



- 1000h QUV
- Epoxy-functional Silane Oligomer increased initial & aged tensile strength by 20-30%
- Amine-functional Silane Monomer reduced initial tensile strength that was regained upon aging

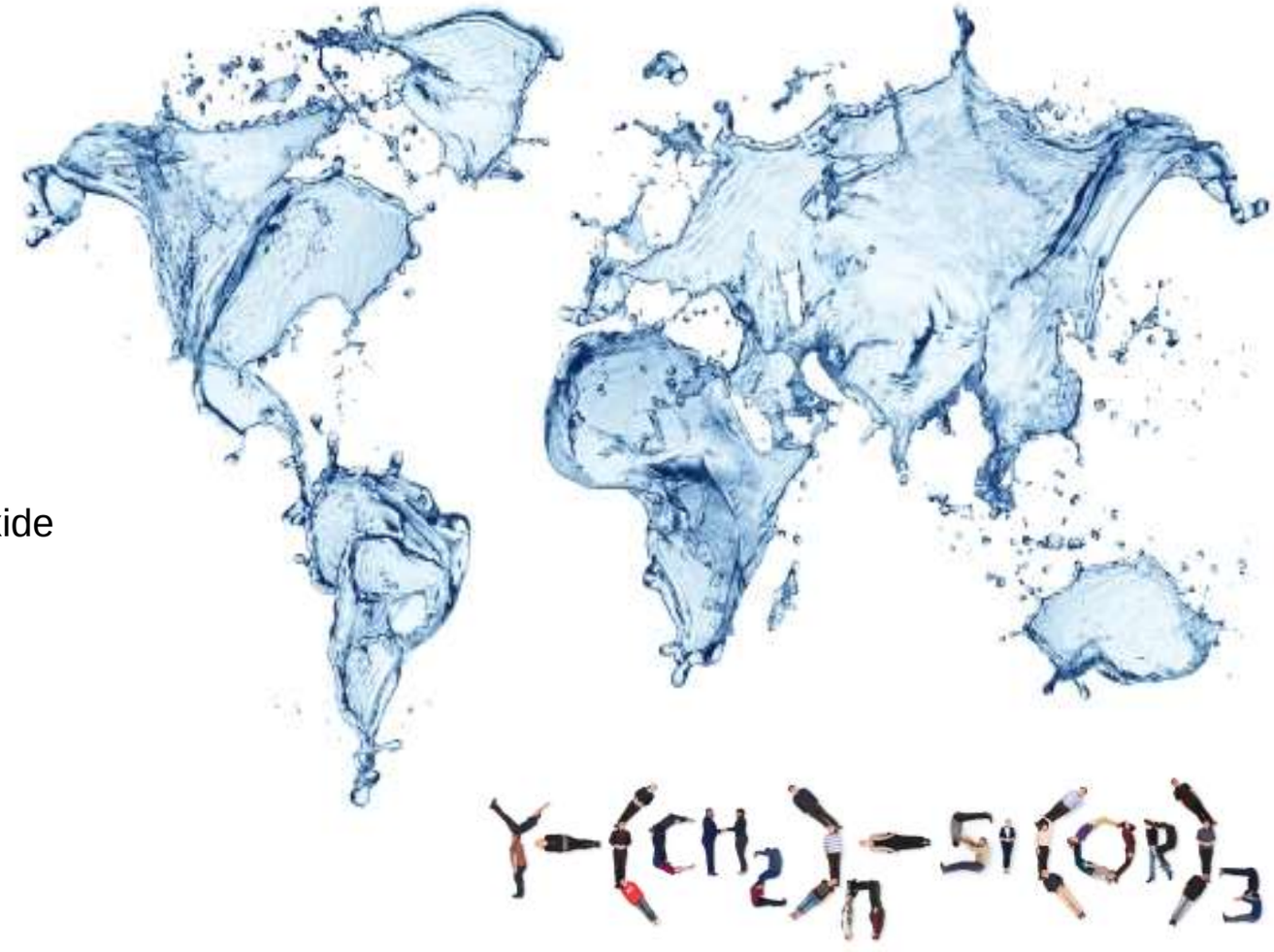
Coating Appearance, Aged – Silanes in Waterborne Acrylic Roof Coating



- 1000h QUV on aluminum panels
- All coatings were free of defects

Silanes for Acrylic Roof Coatings

- Resist ponding water
  - Reduce water uptake 60-70%
  - Increase wet adhesion to EPDM 130-150%
  - Increase wet adhesion to PVC 20-45%
  - Prevent delamination and blistering
- Reduce staining
  - Improve removal of carbon black and iron oxide
- Increase durability
  - Better flexibility and tensile strength
  - Improve weather resistance
- Shelf stable
- Immediately available & TSCA listed



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