Correlation in Accelerated Testing

Principles, Challenges and Case Studies

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We hope you found our webinar on Correlation in Accelerated Weathering and Corrosion Testing to be helpful and insightful. The link below will give you access to the slides and recorded webinar.

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We consistently hold seminars and webinars about weathering, corrosion, standards and more. The best way to keep up with news and events is by following us on Facebook, Twitter and LinkedIn.

Today's webinar was part of a weekly series on weathering and corrosion. **New dates and topics have been recently added!** You can register for these new webinars or watch previous ones here.

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The Question

In weathering testing, we encounter the same basic question over and over again …

“How many hours in my accelerated test correlates to __ years of outdoor service?”

The Hard Truth

There is no Universal Acceleration Factor, or "Magic Number," between accelerated and outdoor testing

- Different materials in different service environments have different acceleration factors
- Weathering and Corrosion Tests do not give quantitative predictions of Service Life

Why is this such a challenge?

- The problem is not that we just haven't developed the perfect weathering tester yet.
- The biggest problem is the inherent **variability** and **complexity** of outdoor exposures. Consider just some of the many factors in relationships between outdoor and accelerated tests:

Outdoor factors

1. Latitude
2. Altitude
3. Geography
4. Year-to-year variations
5. Seasonal variations
6. Specimen Orientation
7. Environmental particulates

Laboratory factors

8. Specimen insulation
9. Test cycle
10. Water delivery
11. Test temperatures
12. Light source

And of course…

13. The particular materials system tested

What Can Be Done

- Weathering and corrosion testing can have many goals other than determining acceleration factors and service life.
- Determine what you need to know for your materials and select an appropriate test program
- Although weathering and corrosion tests usually are not ***predictive***, they can often be ***correlative***
- **Weathering and corrosion tests are comparative, and comparative data can be powerful.**

Accelerated Testing is a **Tool for Decision Making**

Accelerated tests can help you …

- What ingredients to include or not include in a product
- Whether a lot or batch is OK to ship to customers
- What vendors to buy from
- What processing and manufacturing parameters should be selected
- **Make better, faster decisions**

Accelerated Test Types

What do we want to learn?

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

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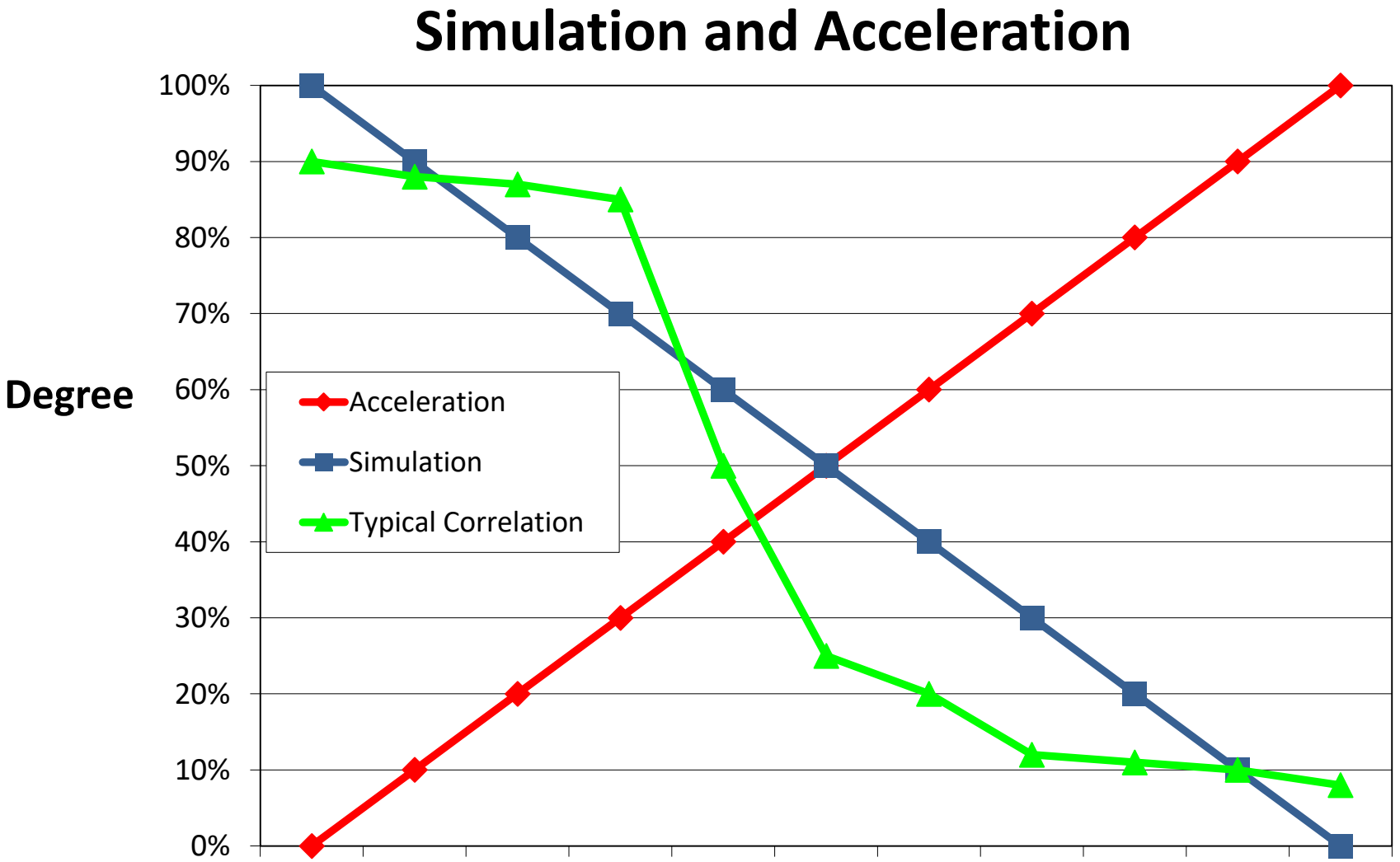
Why is correlation such a challenge?



Correlation

The degree to which sets of data from separate tests agree with one another

- Accelerated vs outdoor weathering
- One accelerated test method vs another
- One outdoor environment vs another

Why Correlation Matters

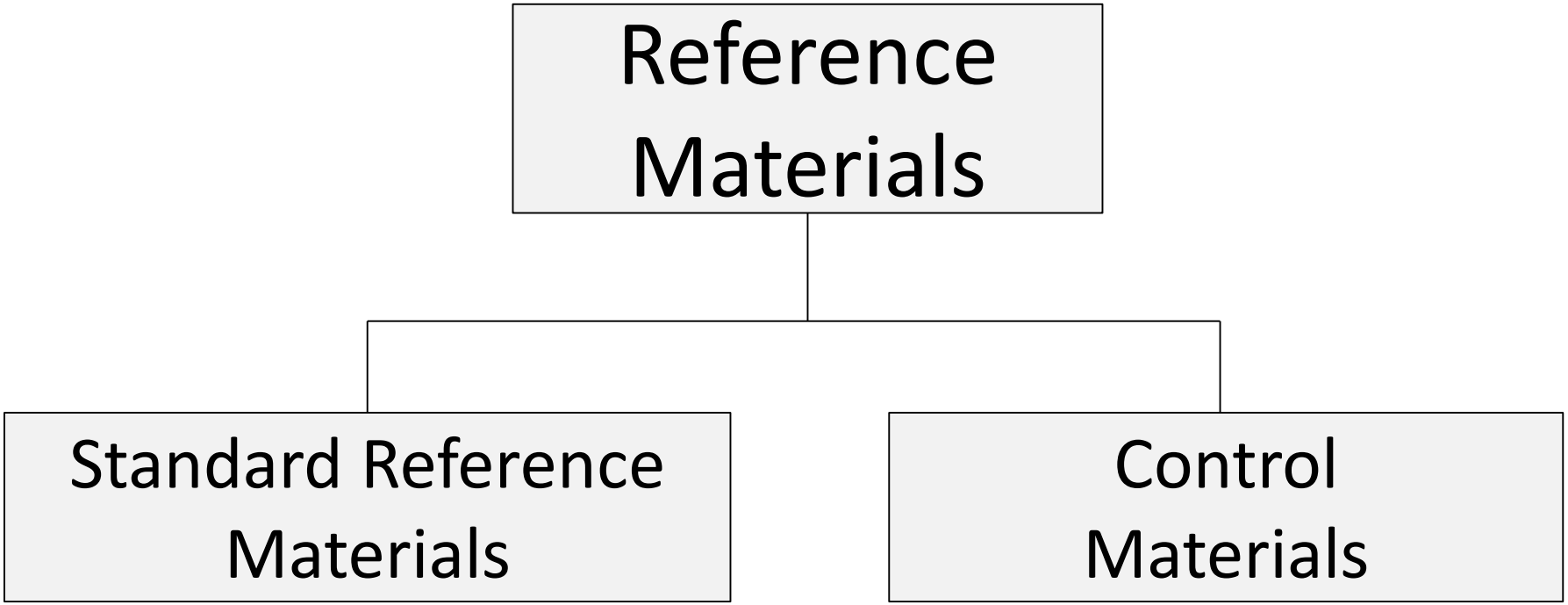
- Decision-making tools need to be validated
- There is an inherent conflict between acceleration and realism
- The only way to validate an accelerated weathering test is with outdoor/real world data
- **In other words … Test the Test!**

Methods for Establishing Correlation

Two main methods for correlating two tests (usually outdoor and accelerated)

- Reference and Control Materials
- Rank Order Evaluation

Reference and Control Materials

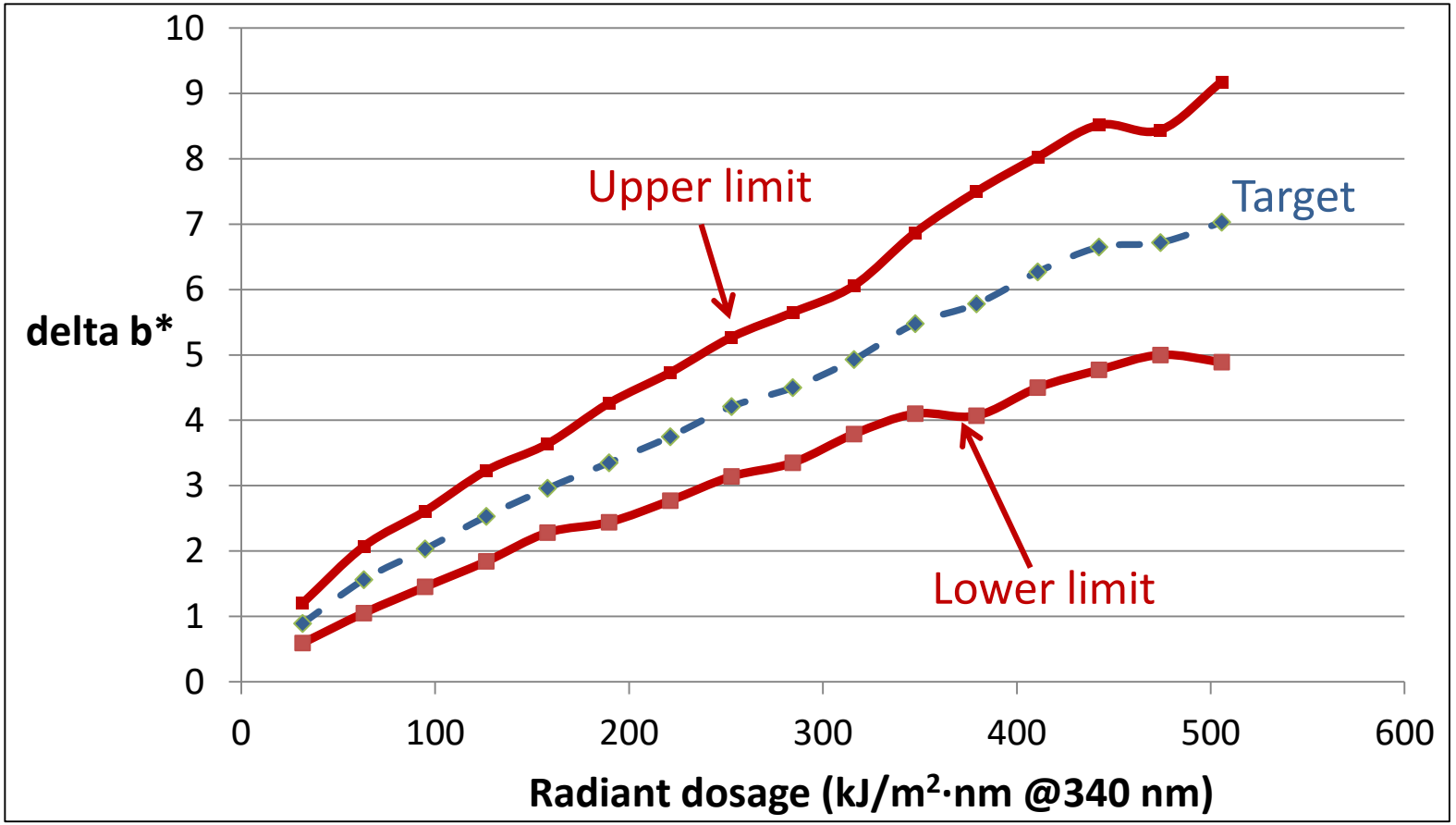


- Known performance in test environments
- Not necessarily similar to test specimens
- Performance may not match test specimens
- Verify that lab tester is operating properly

- Similar characteristics to test specimens
- May be your products or competitors'
- Give confidence in lab exposure

Standard Reference Material

Example: Polystyrene (PS) yellowing for SAE J2527



Reference Polystyrene yellowing validates tester performance

Control Material Guidelines

- Control materials must have known durability
  - Outdoor performance
  - Lab performance
- Similar **composition** to test material
- Similar **degradation mode** to test material
- Best practice to include both weak- and strong-performing control materials

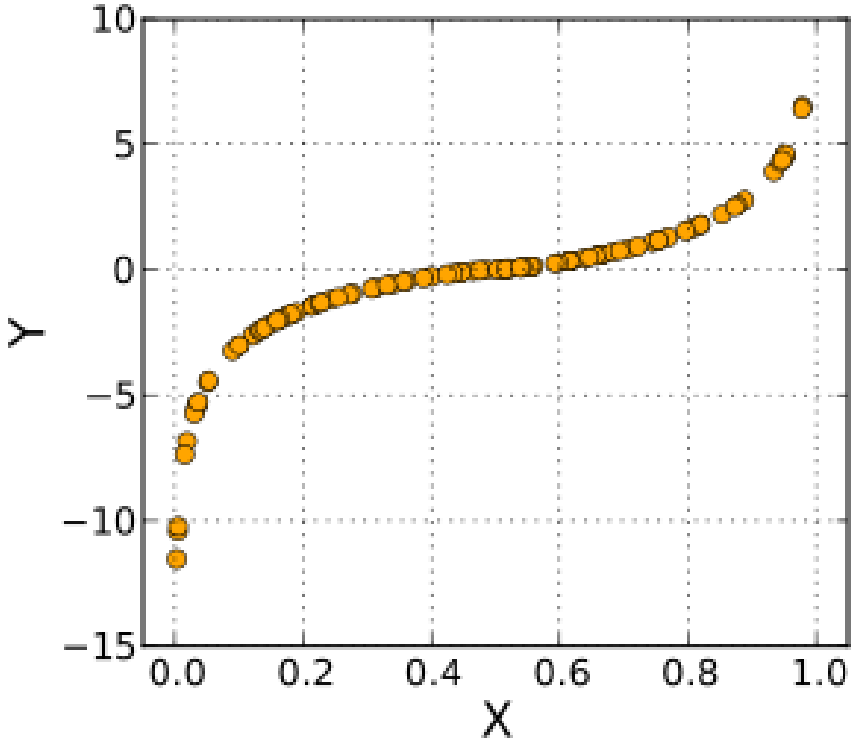
Rank Order Correlation

- Rank materials from best to worst outdoors and in lab test
- Calculate correlation coefficient using **Spearman's Rank Correlation Coefficient**
  - Quantitative measure of how well the lab test matches outdoors
  - Correlation of 1 is perfect (so is -1, in a way)
  - Correlation of 0 is random

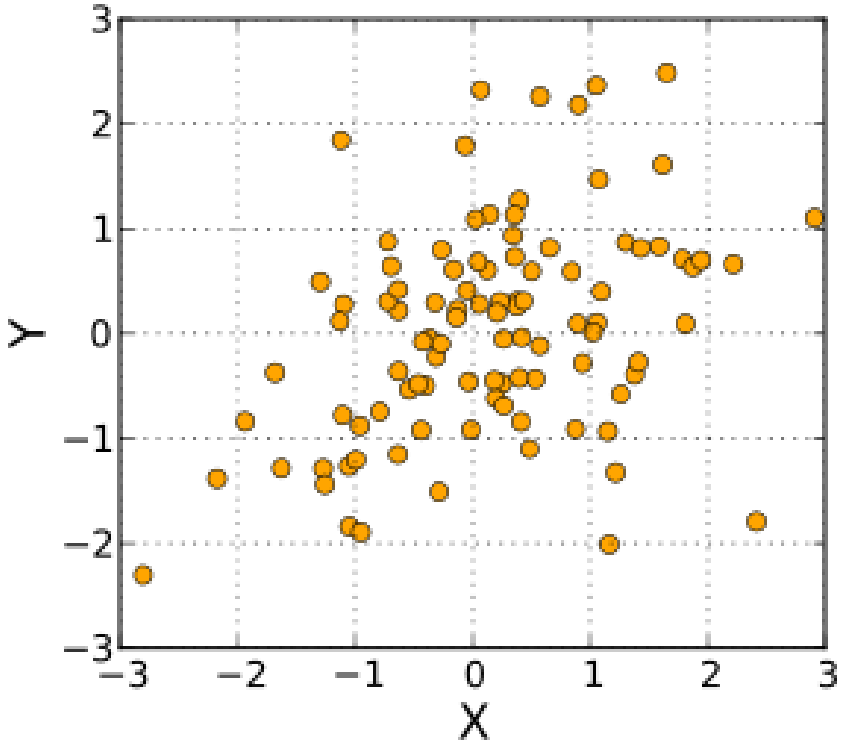
Rank Ordering

Spearman Coefficient

Spearman coefficient:
1.0



Spearman coefficient:
0.35



Rank Order Correlation Benefits

- Determines or confirm relationship between different exposure techniques
- Develops confidence in realism of lab techniques
- Provides a basis for directional decision-making in research and development

Why not Pearson's Product-Moment Correlation?

- Pearson's compares two variables for fit *(e.g. exposure length and degradation)*
- Since most degradation mechanisms are non-linear, Pearson's coefficient is usually poor
- May still be useful in reformulation, once a test is verified with Rank Order Correlation!

Perfect Correlation

Perfect correlation between Accelerated and Outdoor performance is rarely observed

Correlation Case Study #1:

Flexible Bulk Intermediate Containers (FIBC)

Flexible Intermediate Bulk Containers (FIBC)

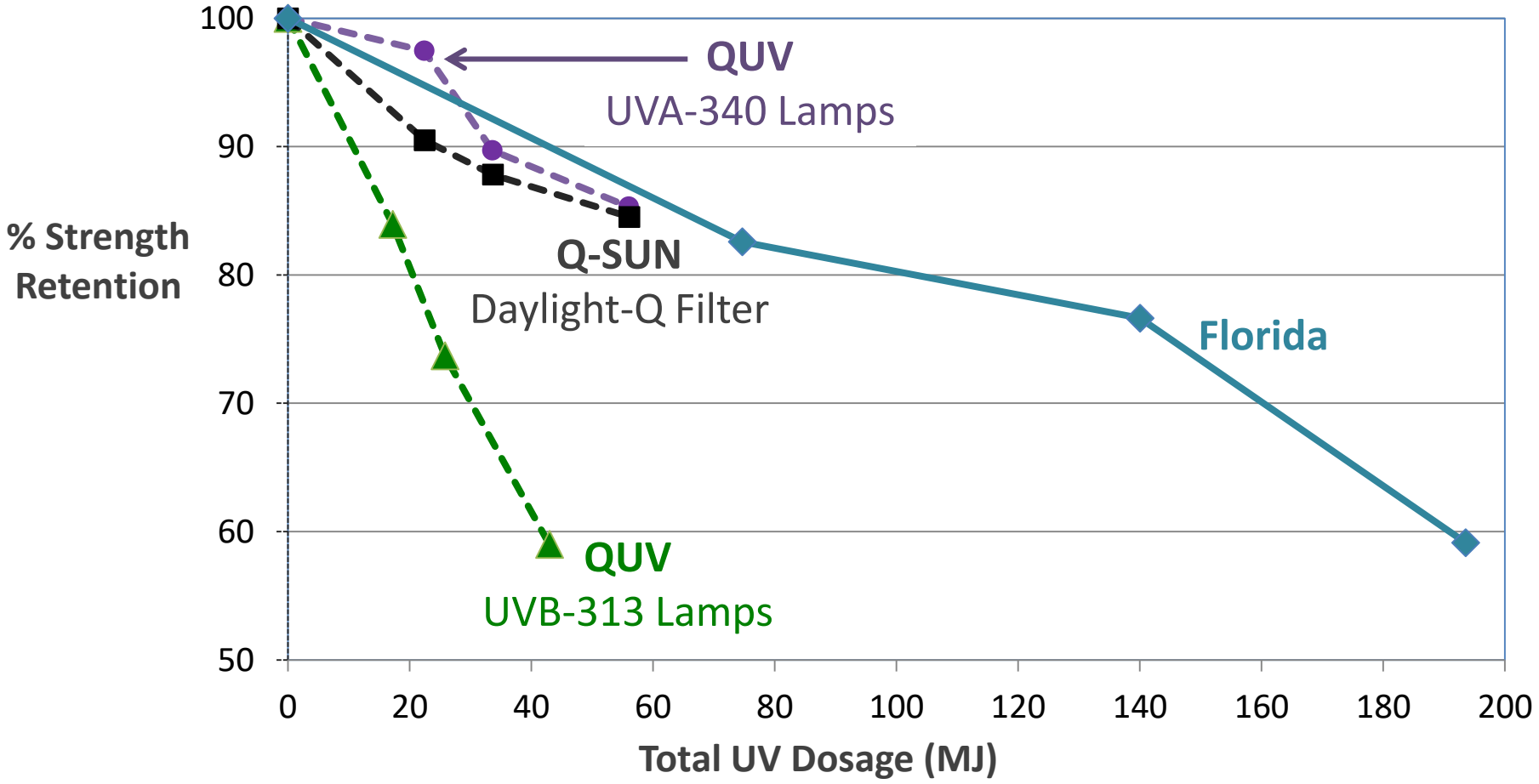
Situation

FIBCs are used to carry goods. They need to survive at a job site for up to 12 months without losing tensile strength.

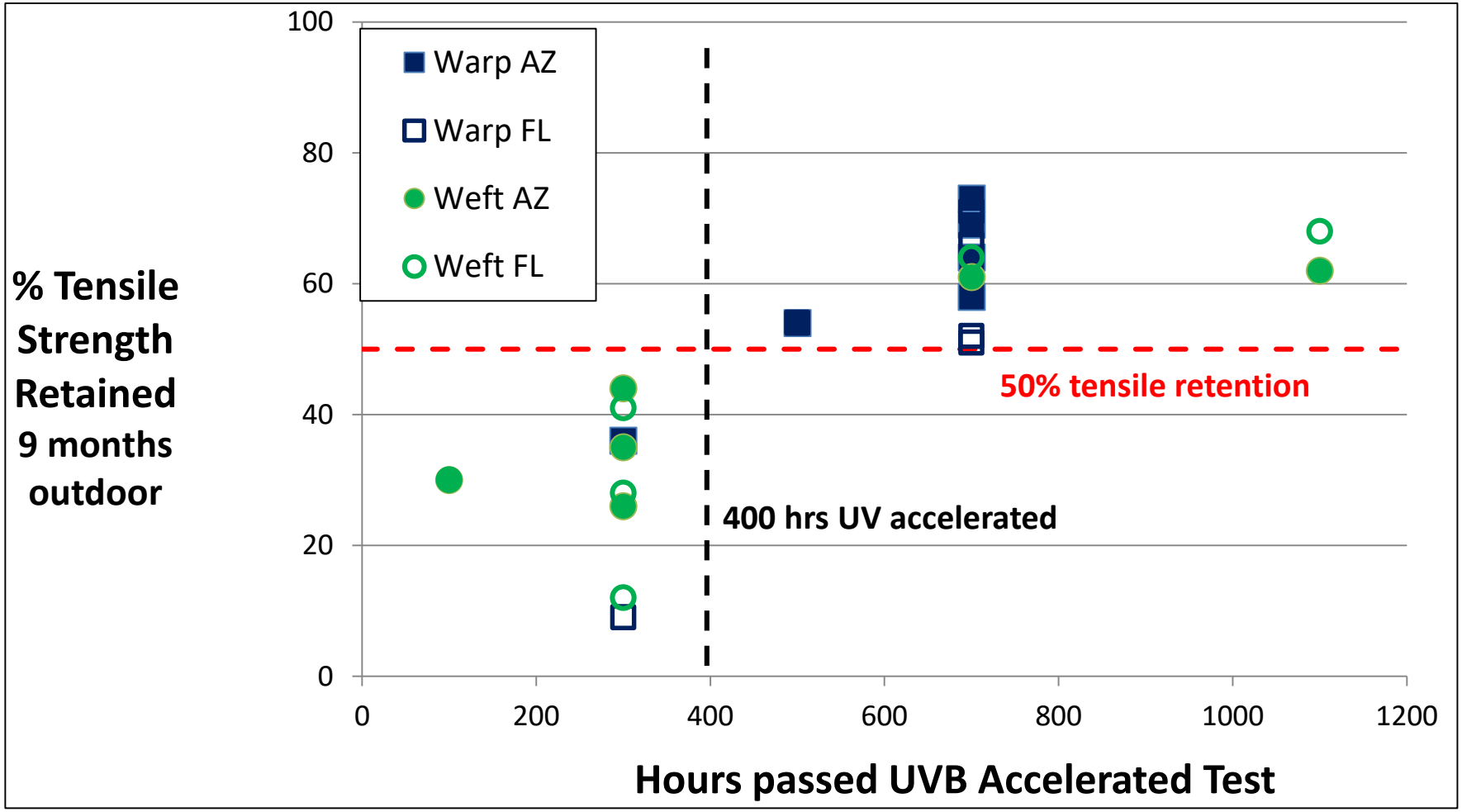
Various test methods with Xenon and Fluorescent UV were compared to outdoor performance.

FIBC Correlative Testing

Accelerated and Outdoor testing – Radiant Dosage



FIBC results: Outdoor/Accelerated Correlation



Very good pass/fail correlation between accelerated and outdoor weathering

Every specimen that survived >400 hours accelerated survived 9 mo outdoors

FIBC Correlation Conclusions

- Xenon arc and fluorescent accelerated testing both provided good correlation to outdoor evaluation
- Realistic light sources (UVA fluorescent, Daylight filtered xenon arc) gave strength retention results that can be correlated to outdoor exposure on a **radiant dosage** basis
  - Acceleration factor ~7: >250 hours xenon testing correlated to 2.5 months in Florida
- Pass/fail behavior of FIBC over 6-9 months predicted well by UVB-313 fluorescent test
  - Acceleration factor ~16: >400 hours lab testing correlated to 9 months outdoors. Pass/fail testing can often be faster!

Correlation Case Study #2:

Artists’ Colored Pencils

Colored Pencils Correlation Study

Background

- There was no standard to distinguish colored pencils' **light stability**

Objective

- Develop standard and determine correlation between natural and accelerated exposures
- Property measured is delta E – total color change

Colored Pencils Correlation Study

Xenon accelerated test data

Color	delta E		Color	delta E		Color	delta E
Red-1	5.7		Yellow	45.6		Blue-1	10.9
Red-1	5.7		Yellow	45.9		Blue-1	11.2
Red-2	26.7		Green-1	6.1		Blue-2	26.8
Red-2	28.5		Green-1	7.0		Blue-2	28.2
Orange-1	79.7		Green-2	5.8		Purple-1	23.0
Orange-1	79.3		Green-2	7.9		Purple-1	22.3
Orange-2	34.8		Green-3	19.3		Purple-2	23.1
Orange-2	34.8		Green-3	19.9		Purple-2	22.9
Beige	19.7		Aqua	5.8		Black	2.7
Beige	19.7		Aqua	5.7		Black	2.1

15 materials – a minimum of 10 (better if 20!) needed for correlation

Colored Pencil Correlation Study

Comparison of accelerated to outdoor

	Arizona Under Glass		Florida Under Glass		Xenon	
Specimen	**ΔE**	**Rank**	**ΔE**	**Rank**	**ΔE**	**Rank**
Red Pigment A	10.9	1	1.3	1	5.7	1
Red Pigment B	45.8	2	36.6	2	27.6	2
Orange Pigment	79.9	3	80.4	3	79.5	3

Results - Rank Order Correlation

Test Rankings Being Compared	Spearman's Rank Coefficient
Arizona – Florida	0.94
Xenon – Arizona	0.95
Xenon – Florida	0.93

Excellent rank order correlation between natural and accelerated exposure results of all of the specimens

Correlation Case Study #3:

Lithographic Inks

Printing Ink Correlative Study

Purpose

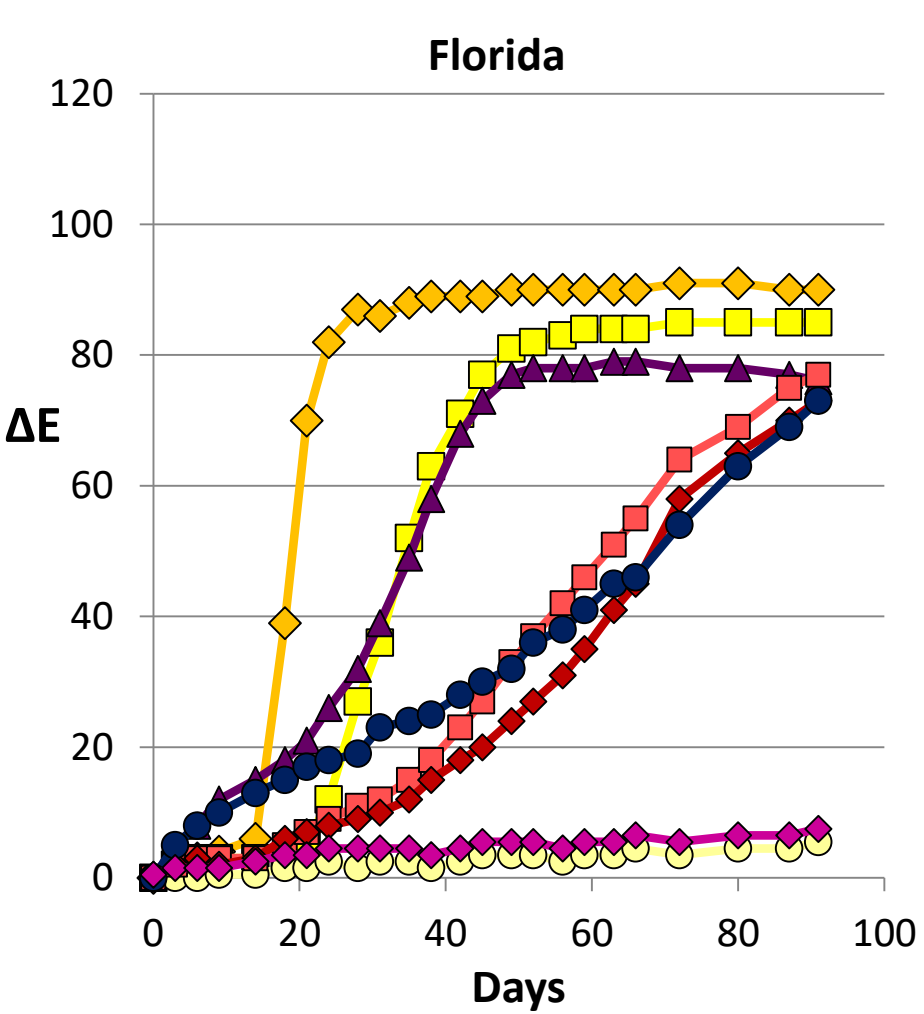
- Evaluate the light stability of lithographic inks

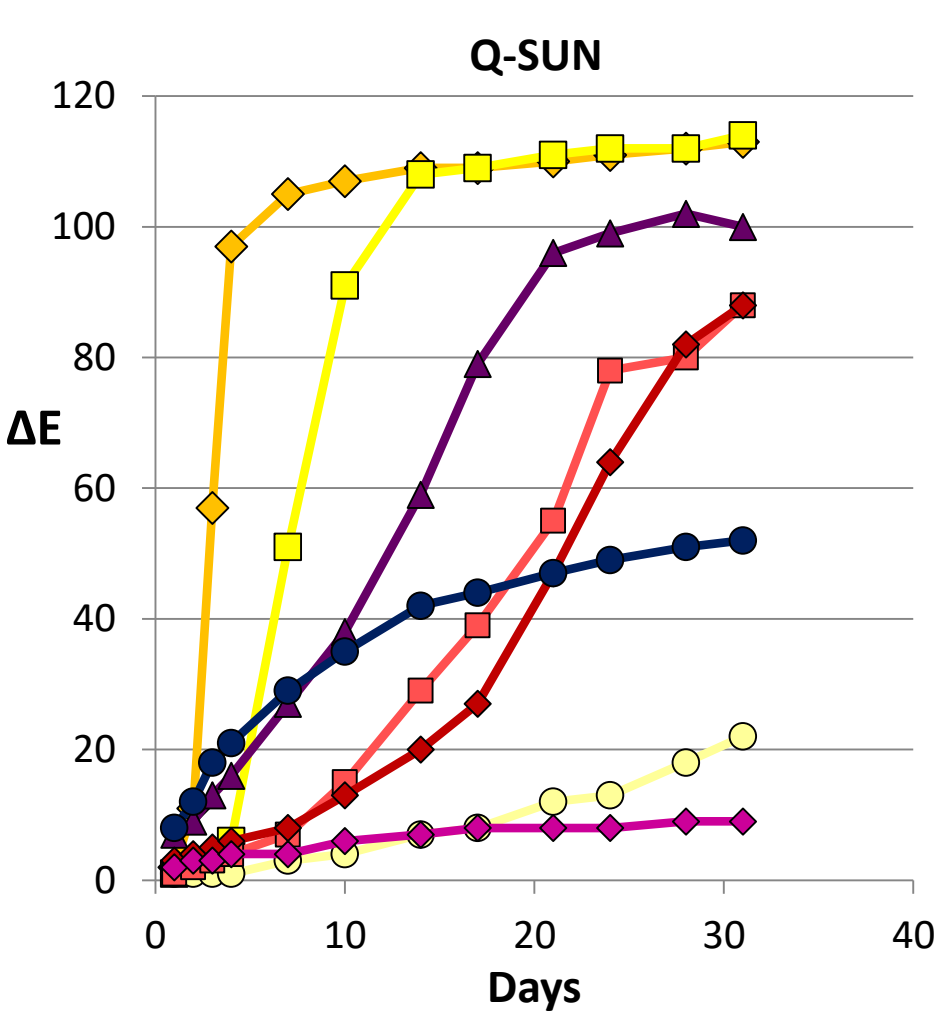
Test Program

- Natural outdoor tests
- Q-SUN Xenon Arc tests

Printing Ink Correlation Study

delta E Color Fade Measurements

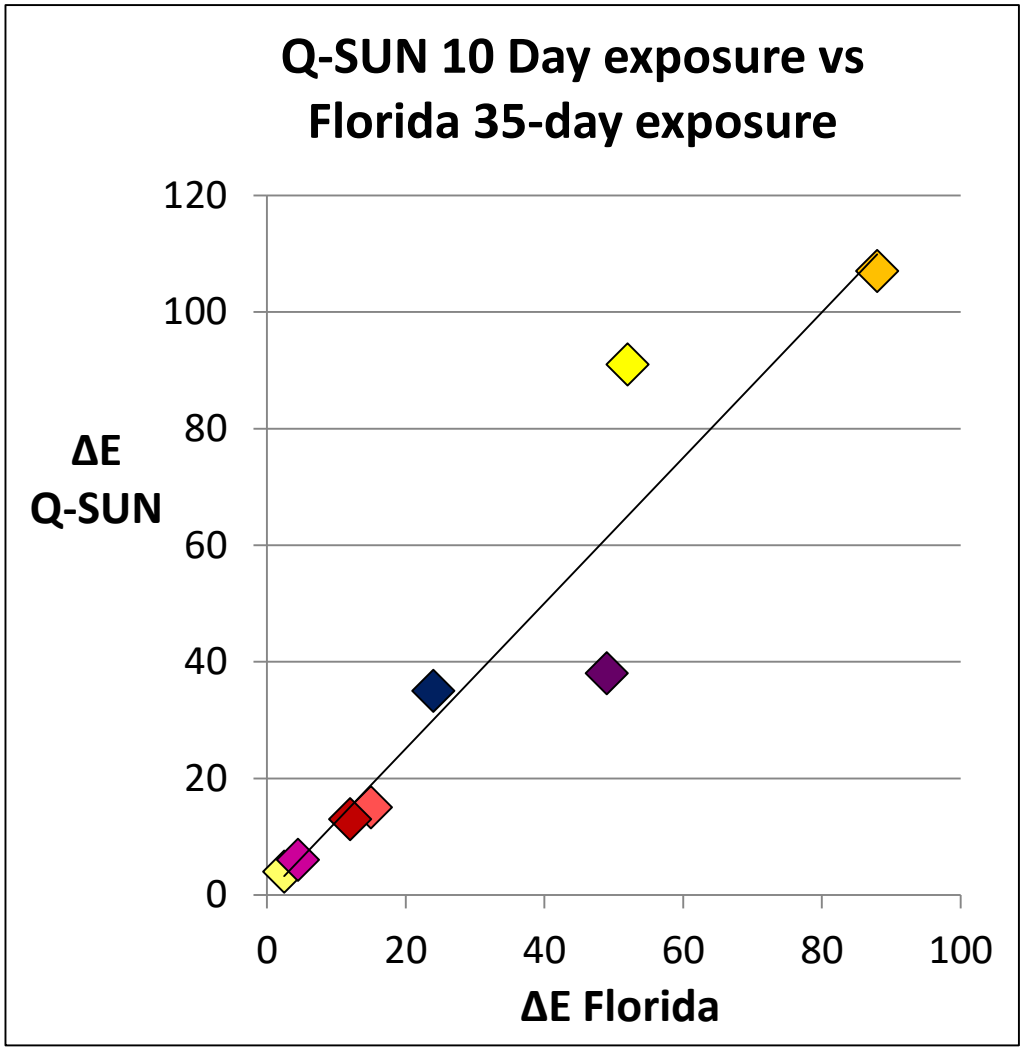




Printing Ink Correlation Study

Conclusions

- Excellent **rank order correlation** between outdoor & lab results
- Test technique can be applied to any ink, ink/substrate combination
- Acceleration factor ~3.5 for these materials under these test conditions



Correlation Case Study #4:

Automotive Coatings tested with ASTM D7869

Transportation Coatings Correlation Study

Situation

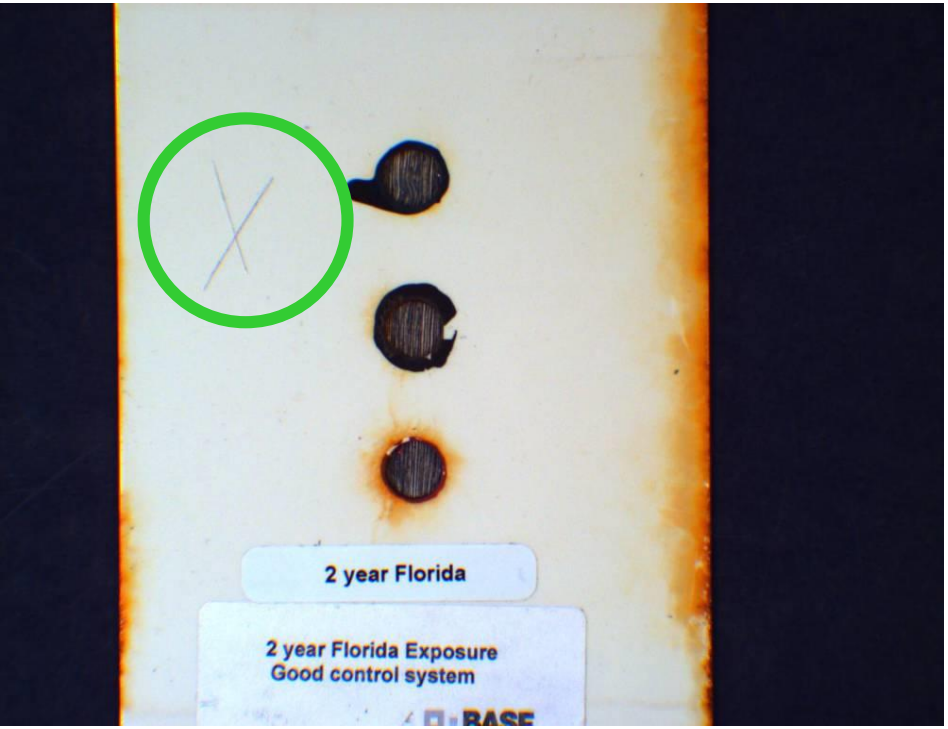
- Widely-used accelerated test standard for auto coatings, SAE J2527, did not reproduce all common outdoor failures. Poor correlation!
- ASTM D7869 developed to provide better correlation between outdoor results and accelerated laboratory tests
- More realistic acceleration of light, heat, water

Test Program

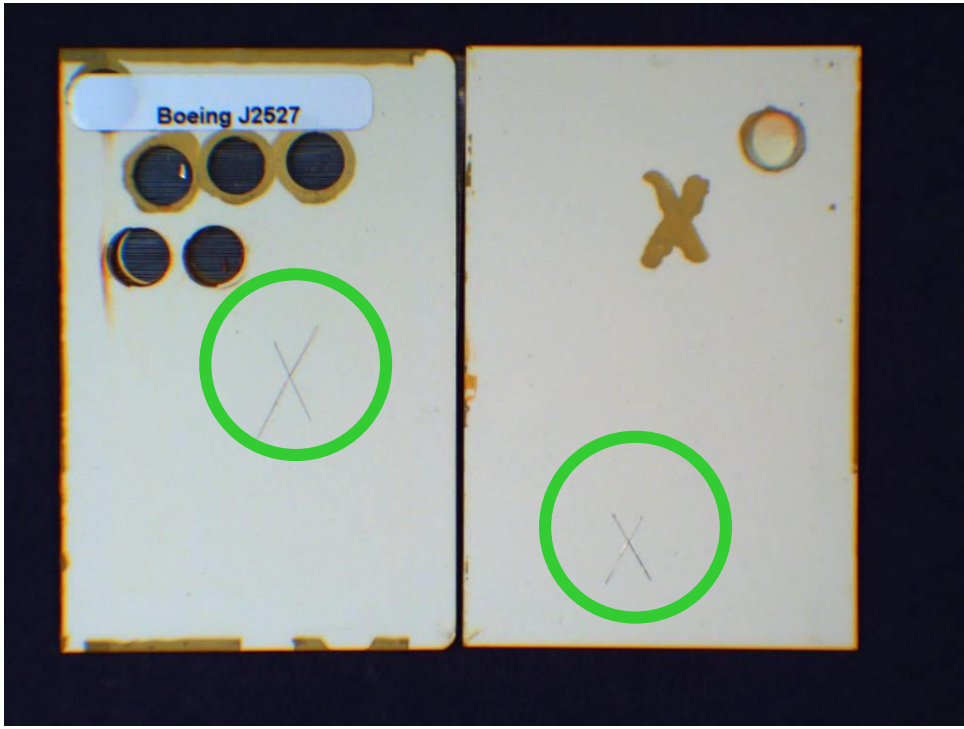
- Over 100 automotive and aerospace coating systems exposed outdoors for two years (~16000 hours)
- Accelerated testing conducted to 3000 kJ (~1800 hours ASTM D7869, ~2300 hours SAE J2527

Correlation results: Control material

Florida Exposure



SAE J2527 ASTM D7869

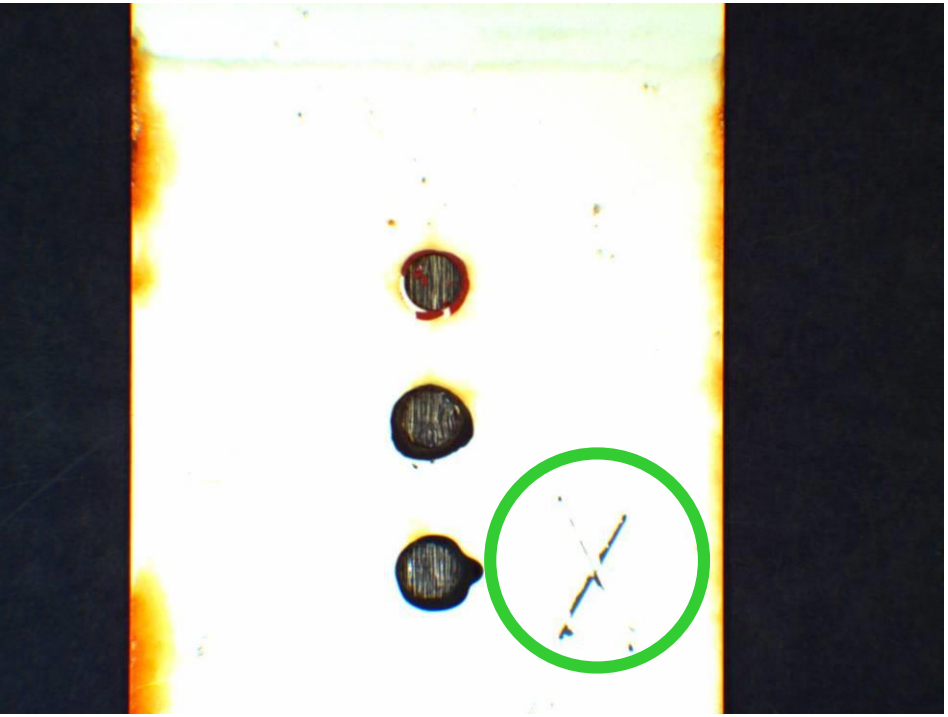


Expected Failure Mode: None – positive control

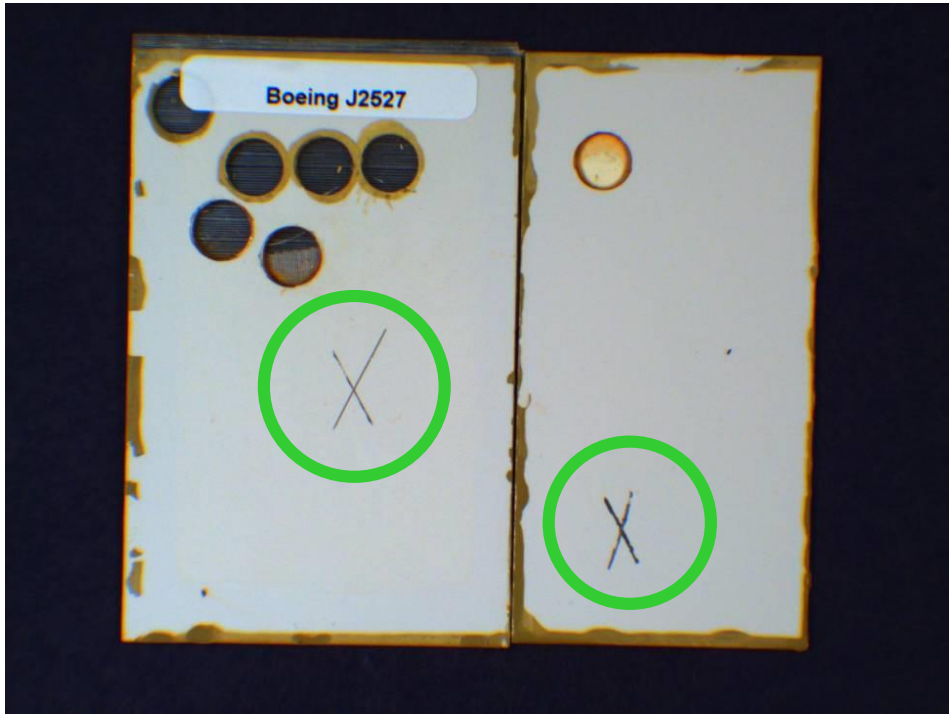
Observed: Excellent performance in all tests

Correlation results: Coating removal

Florida Exposure



J2527



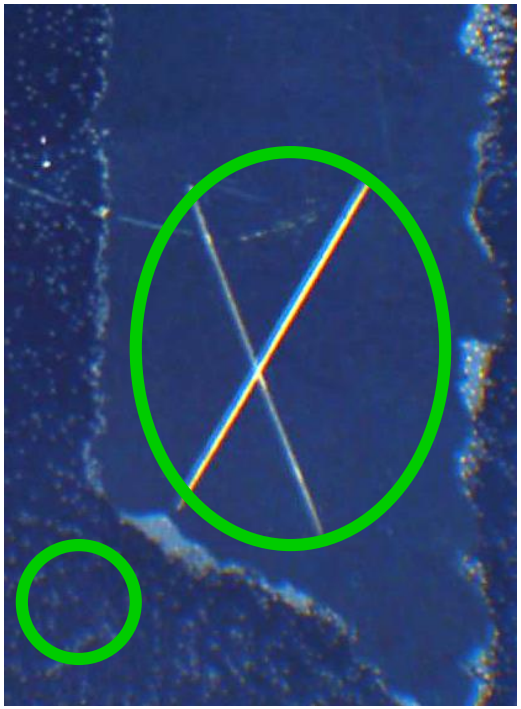
ASTM D7869

Expected Failure Mode: Slight BC/E-coat pick off

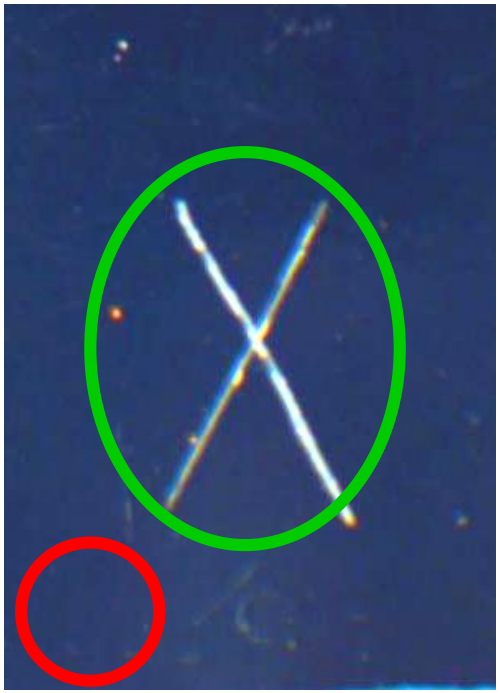
Observed: Slight BC/E-coat pick-off ASTM D7869, not SAE J2527

Correlation results: Delamination

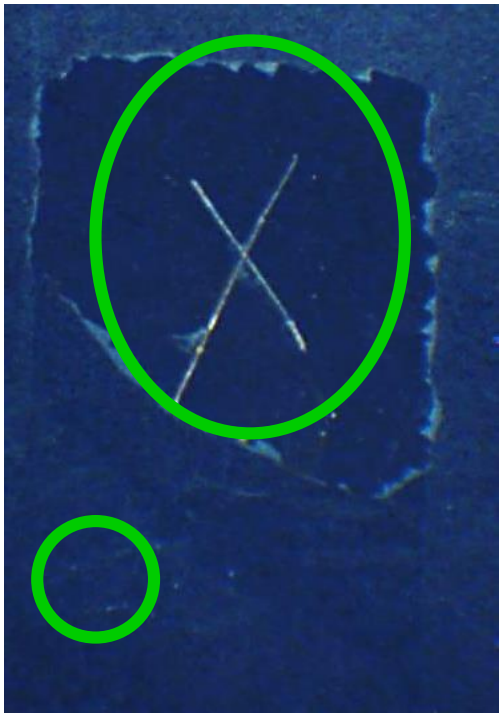
Florida Exposure



J2527



ASTM D7869

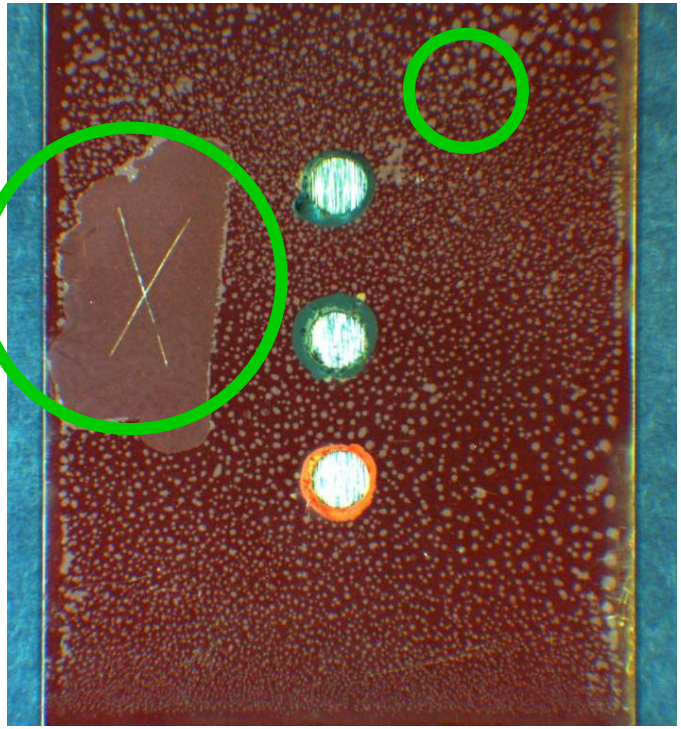


Expected Failure Mode: Blistering, gloss loss, adhesion loss

Observed: Gloss and adhesion loss on both. Blistering ASTM D7869

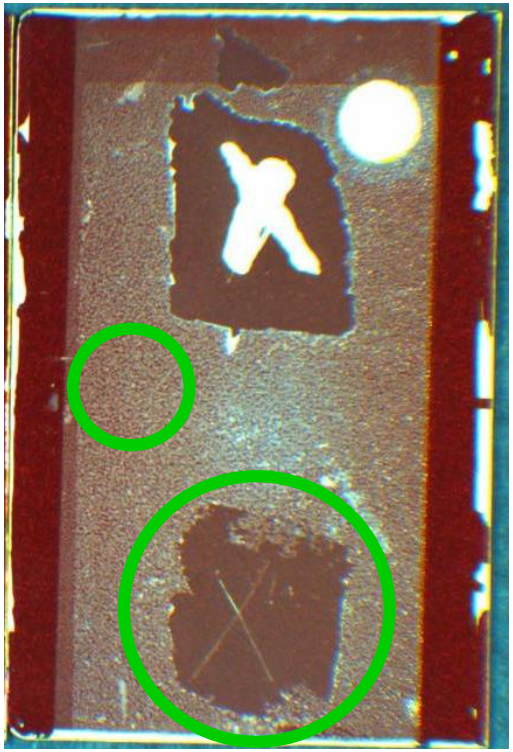
Correlation results: Blistering

Florida Exposure



SAE J2527

ASTM D7869



Expected Failure Mode: Blistering, gloss loss, adhesion loss

Observed: Gloss loss and adhesion loss seen on all panels. Blistering on ASTM D7869 mimics that seen on Florida

Correlation Study for Transportation Coatings

- ASTM D7869 reproduced all major outdoor failure mechanisms – critical for correlation
- **Correlating** degradation between exposures is only valid when the type of degradation is the same!
- 1800 hour accelerated laboratory test results matched well two-year Florida exposures for many coatings systems (acceleration factor ~10)
- May be applicable to other materials systems but **outdoor data has to be collected to verify this**

Correlation Case Study #5:

Vinyl Siding

What is Vinyl Siding?

- Co-extruded building cladding material
  - Manufactured mostly from Polyvinyl Chloride (PVC)
  - Top layer (capstock) is durable and UV-stabilized
  - Also known as uPVC Weatherboarding in some regions

- Developed in the 1960's, became popular in the 1970's
- Most common residential exterior cladding material in US & Canada – about 20 million m^2 used per year

Vinyl Siding Institute

Outdoor test program

- Large-scale, long-term study
- Outdoor data collection ongoing since 1984
- New tests started every 5 years; thousands of specimens and replicates tested
- Long-term material degradation mechanisms are now well understood

Correlation here is between short- and long-term outdoor testing

Vinyl Siding Institute
Service Life Certification

- Accurate service life *estimate* based on 2-year outdoor testing
  - If after 2 years of exposure, color change is <1, then after 25 years it has a high probability of color change <4
  - Acceleration for service life prediction of 12:1
- 2 year outdoor certification program
  - Administered by ISO 17025-accredited, independent 3rd party
  - Exposures in FL, AZ, OH
  - Tests performed in accordance with ASTM test standards
  - Receive a VSI stamp, gives credibility to a 25-year warranty

Qualification / Correlation Case Study

Vinyl Siding Institute (VSI)

- **New Goal**: Correlate accelerated test to 2-year outdoor results
- Six rounds of accelerated testing conducted by multiple labs – examined test cycles of both UV fluorescent and xenon
- Unique Fluorescent UV cycle provided best correlation for PVC siding material
  - Hot condensation best for accelerating realistic moisture attack synergistically with UV
  - Long wave and visible had little impact
  - Reduced UV temps and increase condensation temps gave better results
- UV fluorescent test not adopted for certification program, but used by members for product development

Summary of Correlative Testing

Accelerated Test Types

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	**Rank-ordered data**	• **Open-ended** • **Medium**	**Natural exposure (Benchmark site)**
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

What did we learn from those correlation case studies?

All of the acceleration factors were different! They are not general or universal and they depend on:

1. The specific material tested.
2. The type of test being correlated to natural outdoor results – fluorescent UV, xenon, accelerated outdoors
3. The specific set of lab tester time cycles and temperature.
4. The specific outdoor exposure site and sample mounting procedure
5. The failure mechanism(s) being evaluated

Correlation between accelerated and outdoor testing

Correlation between outdoor and accelerated testing can be determined for a variety of materials systems. However…

- Acceleration factors are not general and often only valid for one type of degradation
- Comparative testing usually gives rank-ordered data, which can be powerful data
- It is **critical** to perform outdoor testing to validate accelerated testing - **“Test the Test”**

Thank you for your attention!

Questions?

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