Improving Accelerated Weathering Protocols to Anticipate Florida Exposure Behavior of Transportation Coatings

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Service Life Prediction of Polymeric Materials: Vision for the Future
Monterey, California
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Outline

Introduction

- Overview of exterior coating systems
  - Automotive
  - Aerospace
- Objective & Approach
- Coating Systems Tested
  - Basecoat-Clearcoat
  - Monocoat

Experimental Study and Results

- Weathering Considerations
- Weathering Protocols
- Results
  - Chemical degradation
  - Physical failures
  - Gloss loss

Summary

- Conclusions
- Closing Remarks

Importance of Exterior Coatings

Appearance

- Pride of ownership
- Critical element of image/ branding

Durability

- Corrosion control
- UV, abrasion, fluid resistance

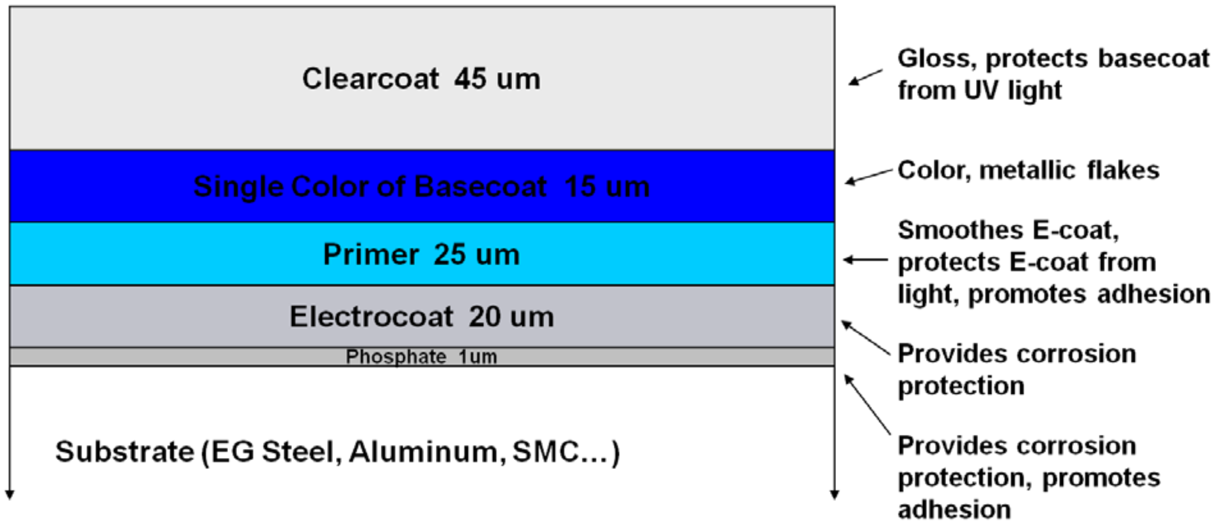
Macroscopic Impact of Coating Degradation

Cracking / delamination:
Unhappy Customers

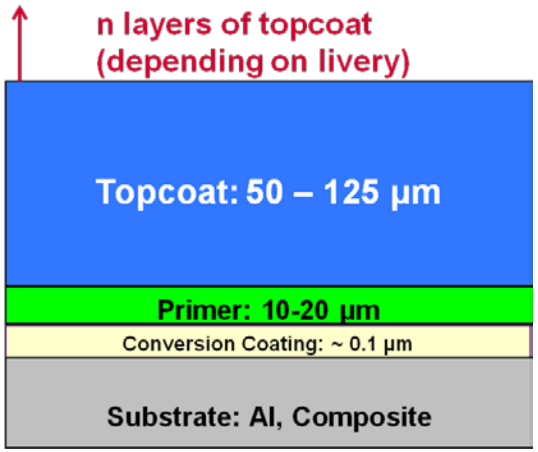
Color shift and loss of gloss:
Unhappy Customers

Multilayer Coating System Types

Automotive:
Basecoat-Clearcoat

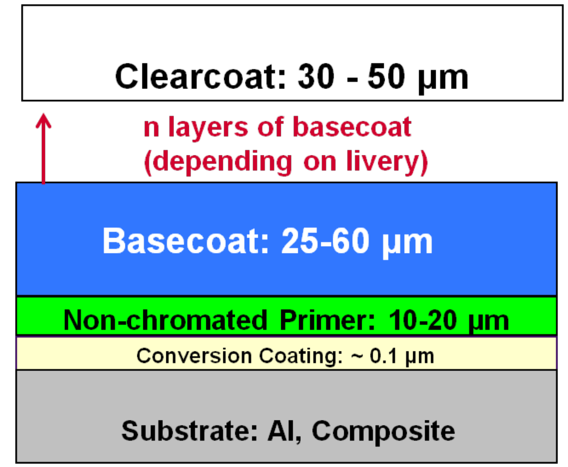


Aerospace:
Conventional (Monocoat)



Challenges:
- Flow Time
- Over coat window
- Fluid resistance

Aerospace:
Future State (BC/CC)



Objective & Approach

Develop an accelerated weathering test for transportation coatings that improves over SAE J2527

- **Rapid** – Goal is 10X acceleration over natural weathering => Higher intensity light than SAE J2527, but keep temperatures realistic
- **Accurate** – minimal false positives and false negatives
- **Machine Agnostic** – able to run test protocol in a variety of accelerated weathering devices
  - 2 manufacturers, 10 machines, multiple locations
- **Minimal sample investigation** after exposure

South Florida is the target to reproduce

- Match Spectral Power Distribution cut-on
- Account for time of wetness ~12 hours/day in Florida
- Scale dosage to diurnal cycles – short light and short wet cycles *(Conflicts with need for longer wet times)*
- Never spray panels when light is on *(Doesn't rain while the sun is shining brightly)*
- Check aerospace coating results against fleet surveys

Transportation Coating Systems Tested

Automotive

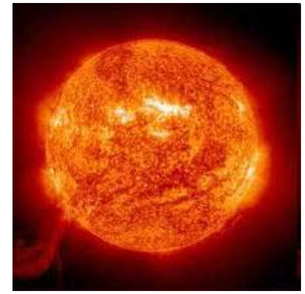
- ~20 systems, multiple colors
- All systems were BC/CC
    - Acrylic melamine, Carbamate, 2K Polyurethane
    - Solvent borne and water borne basecoats
- Fortified and unfortified
- Positive controls and known Florida exposure failure mechanisms

Aerospace

- Three systems in blue and white
- Two monocoat, one BC/CC
    - All 2K Polyurethanes
    - All solvent borne
- Florida and in-service performance known

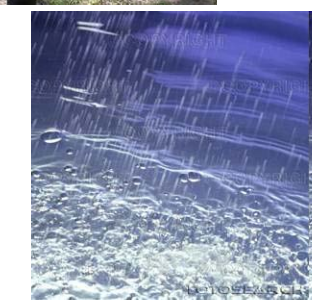
Weathering Environmental Stressors

- **Light - Ultraviolet Radiation**
  - UV at sea level
  - UV at 40,000 feet



- **Heat – Arrhenius Dependence**
  - As high as 80 °C at sea level
  - As low as -50 °C at 40,000 feet

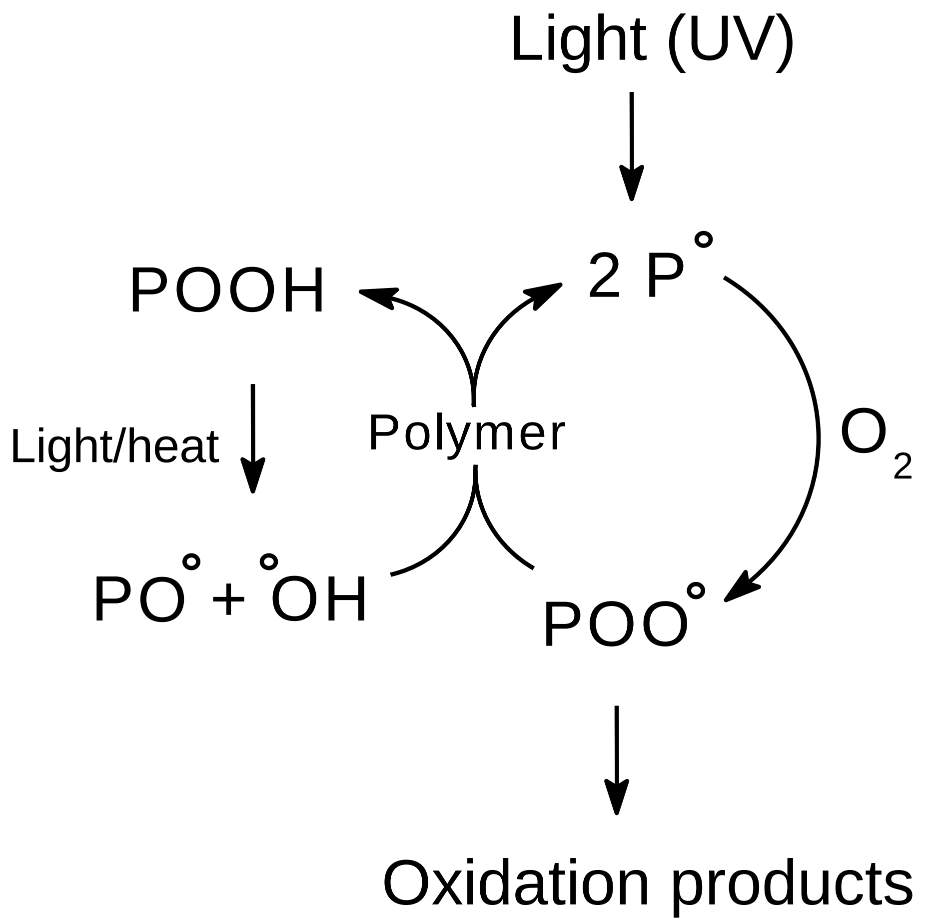
- **Water/Moisture**
  - Variable/cyclical at sea level
  - Bone dry at 40,000 feet



- **Pollutants**
  - Particulate
  - Acid Rain (pH)
  - Volcanic & Industrial

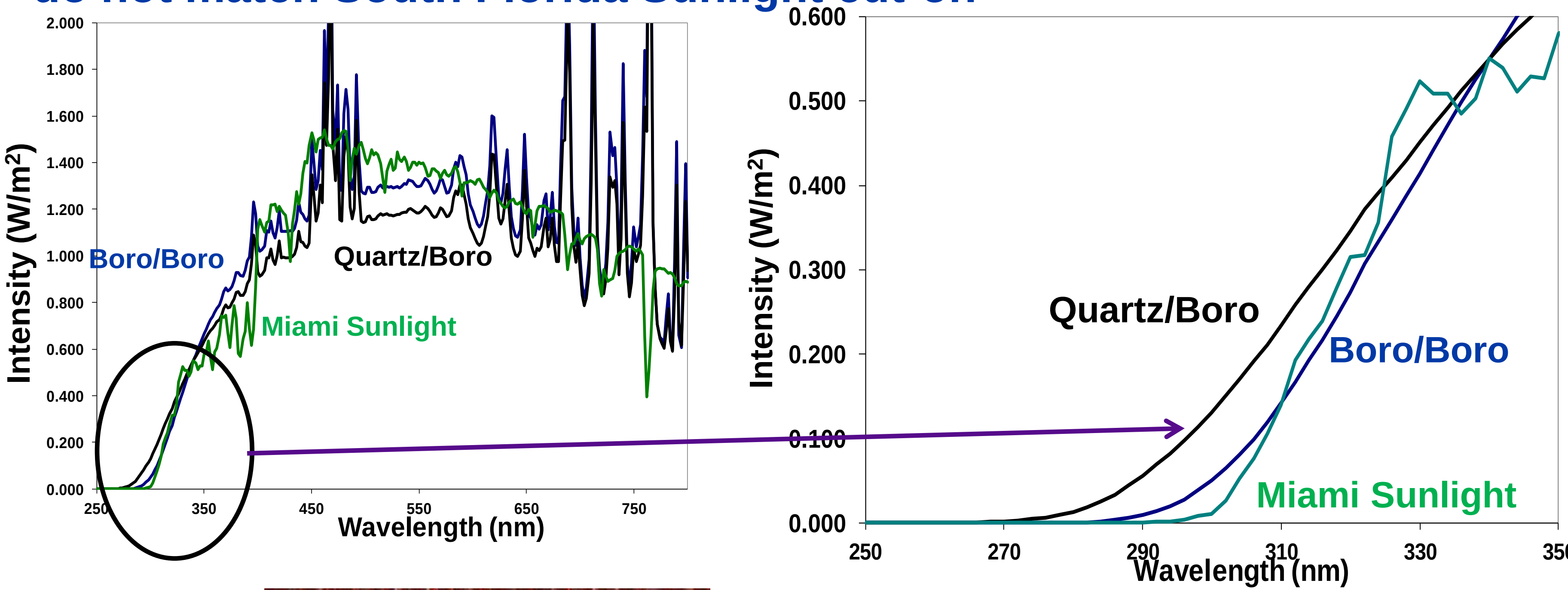
Photo-oxidation Chemistry

- Photo-oxidation chemistry drives changes in physical properties
- Other environmental stressors acting on paint system then cause the system to eventually fail.
- Radicals are stabilized by fortifying coating – ex. UV Absorber

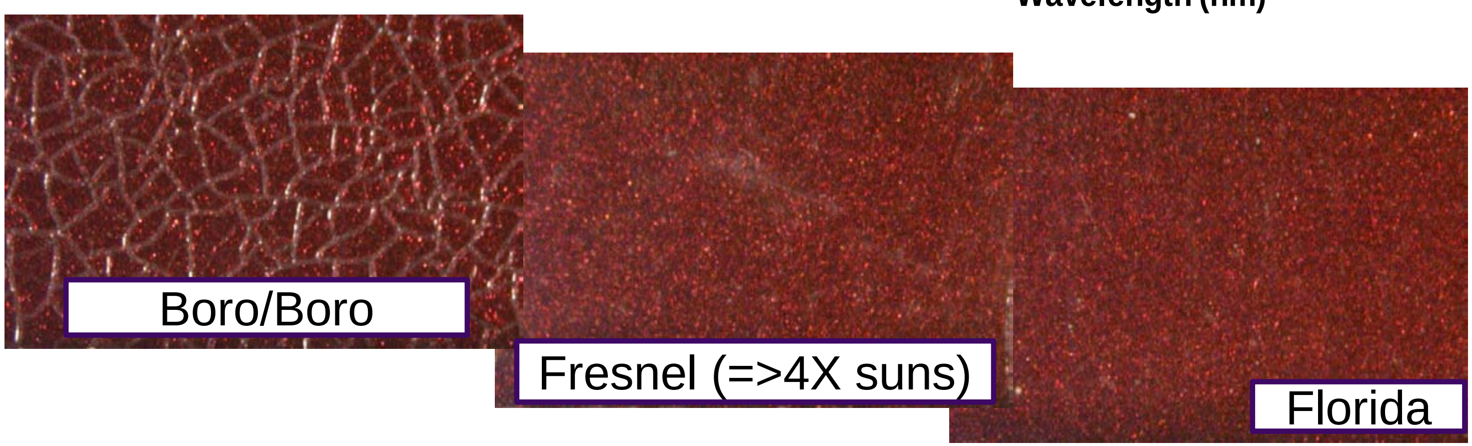


Spectral Power Distribution Mismatch Example

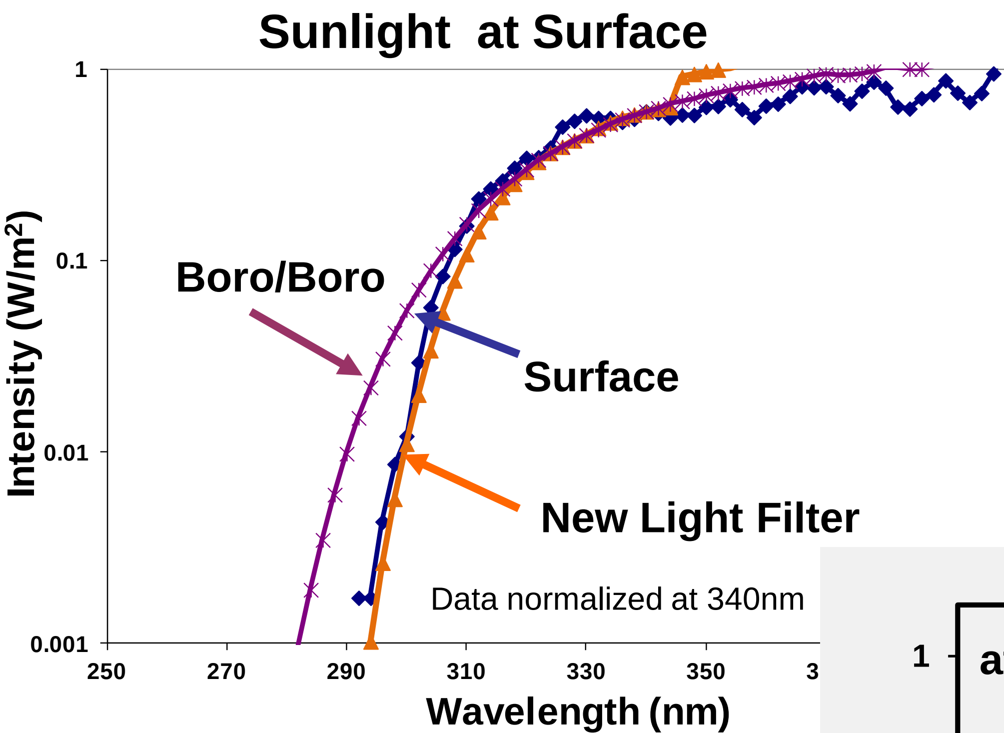
SAE J2527 Extended UV (Quartz/Boro) & Daylight (Boro/Boro) filters do not match South Florida Sunlight cut-on



Polyurethane Basecoat-Clearcoat automotive coating

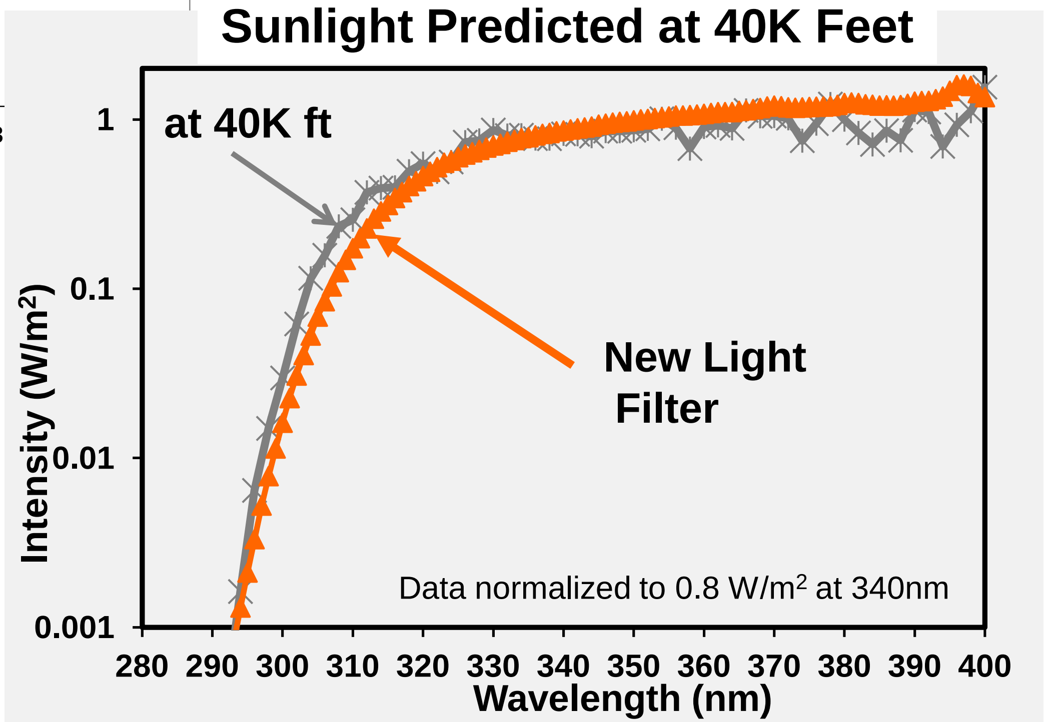


SPD of South Florida at Surface & 40k Ft.

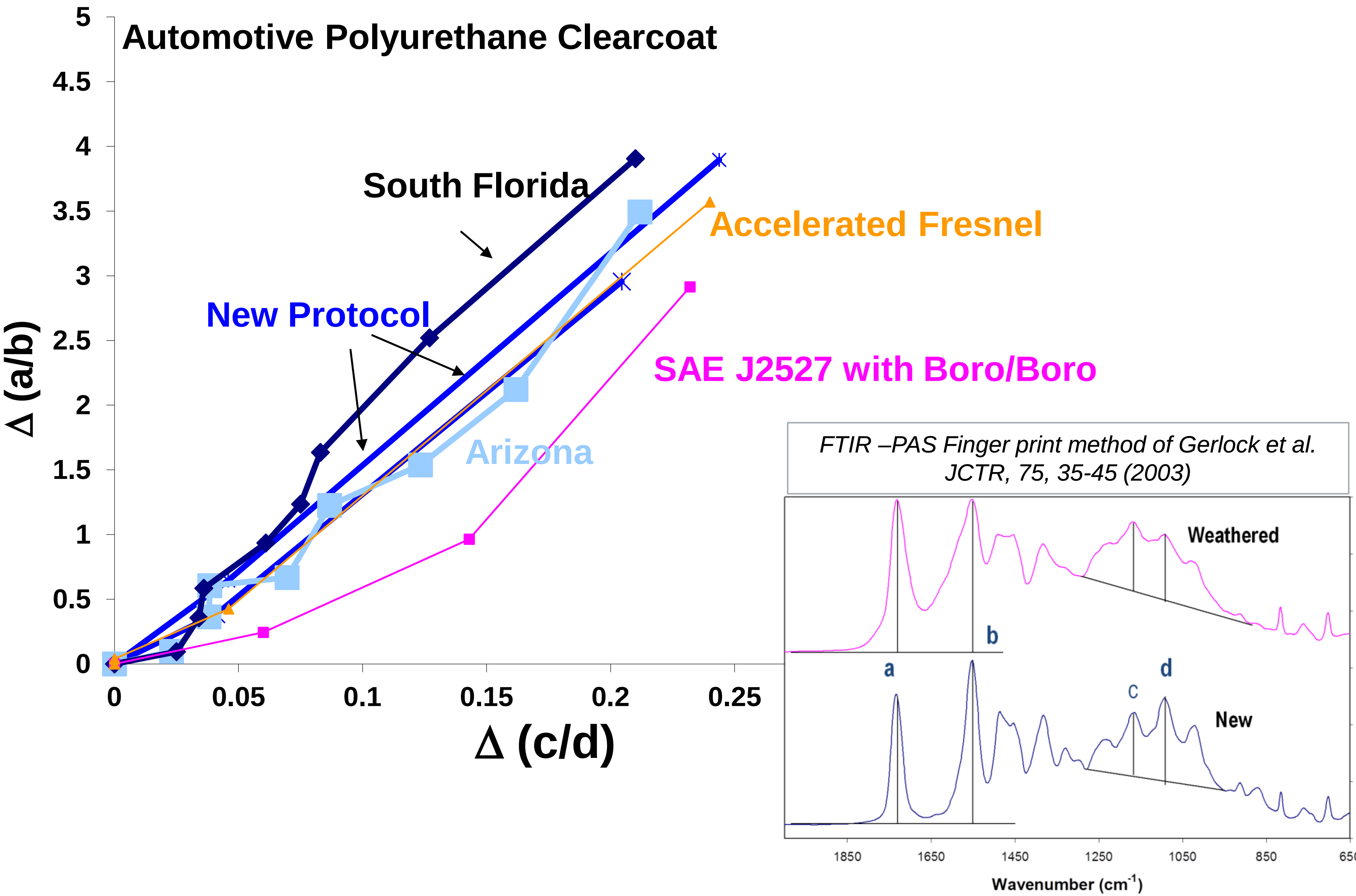


New Light Filter

- **Matches cut-on and irradiance shape of Miami surface or at 40K Feet**



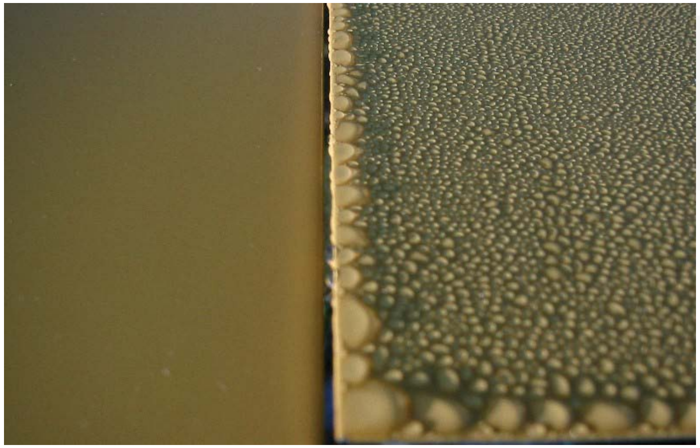
Chemical Degradation Match using New Filter



Effects of Water on Coatings during Weathering

- Plasticization – reduced modulus and Tg
- Swelling – induced stresses due to differential stresses
- Blistering – localized swelling and rupture
- Adhesion Loss – accumulation of water at interface, breakdown of interfacial bonds (hydrolysis).
- Mass transport – movement of small molecules such as HALS and reaction products.
- Mass loss – removal of film (degradation products) from surface of the coating due to erosion.

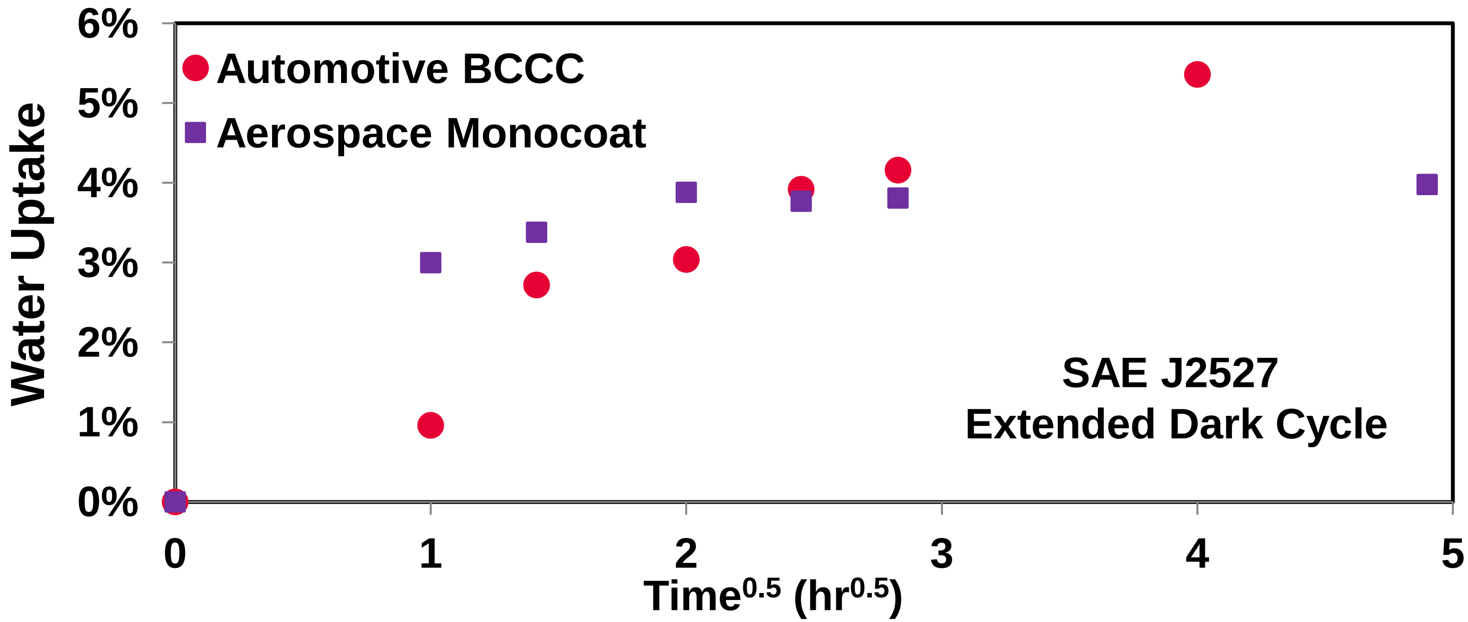
Dry panel (moisture wiped off)

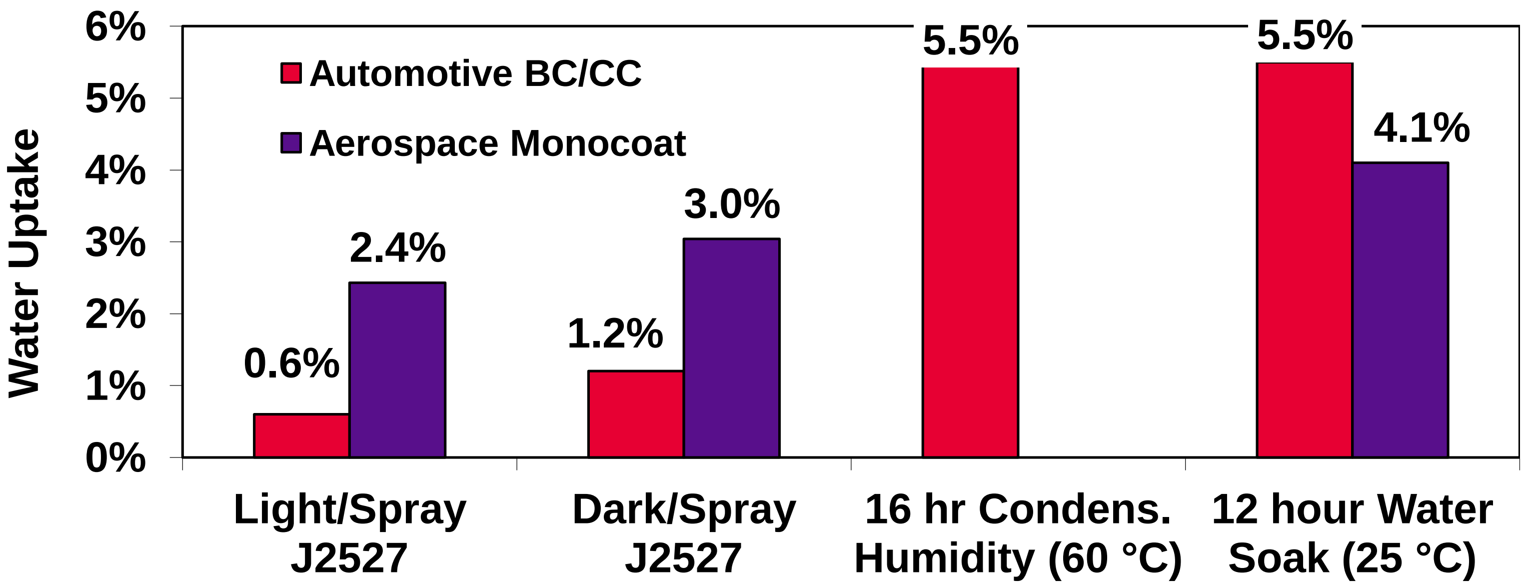


Panel exposed in South Florida in early morning

Photo courtesy of Hardcastle

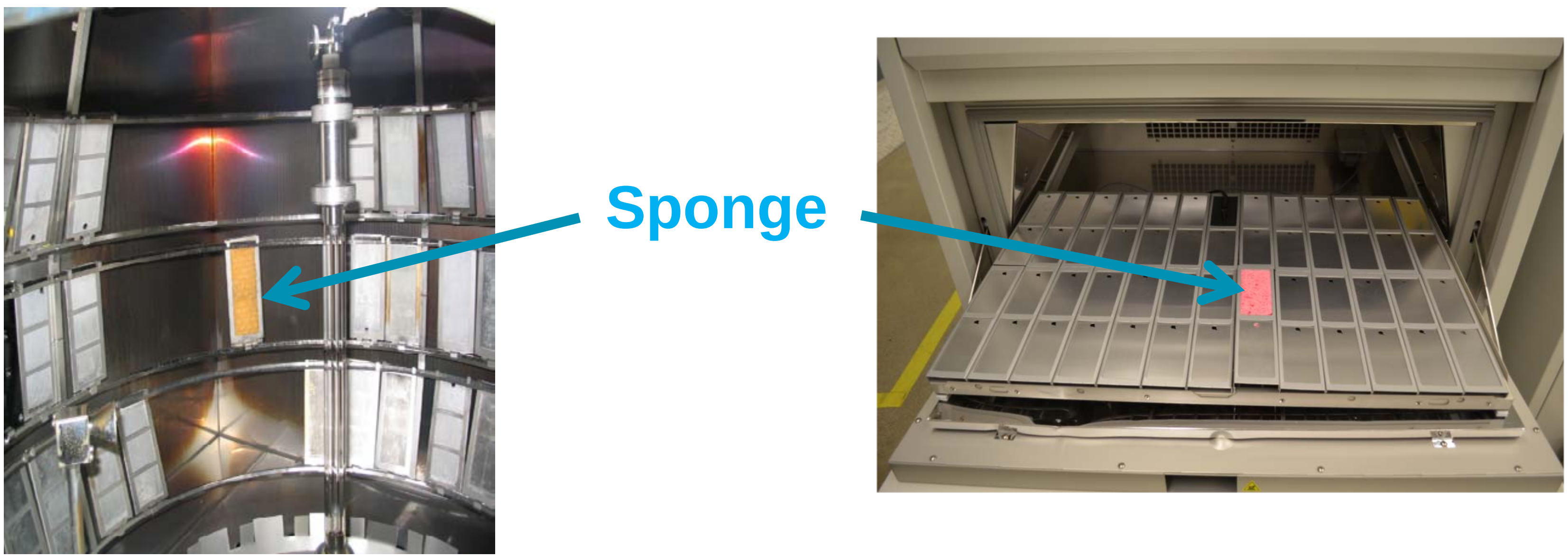
Moisture Absorption in Coatings



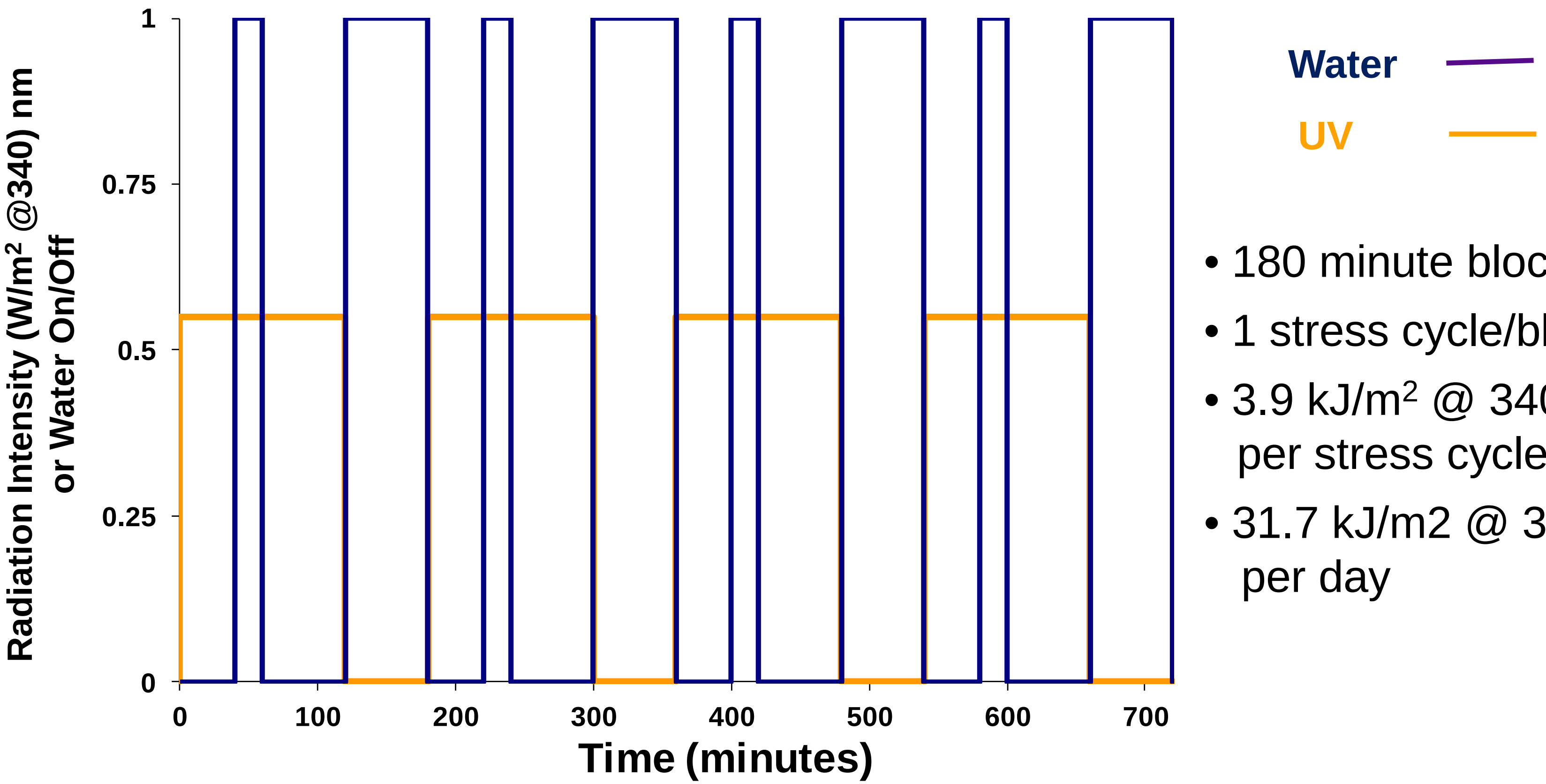


Moisture Absorption – Machine Variability

- Inter- and intra-machine variability minimized by insuring adequate water flow
- Developed “sponge” method to insure water delivery is sufficient to panel site
- Minimum of 10 gm water absorption in 5 minute “dark” spray at 50 °C with sponge in all rows or tiers of machine



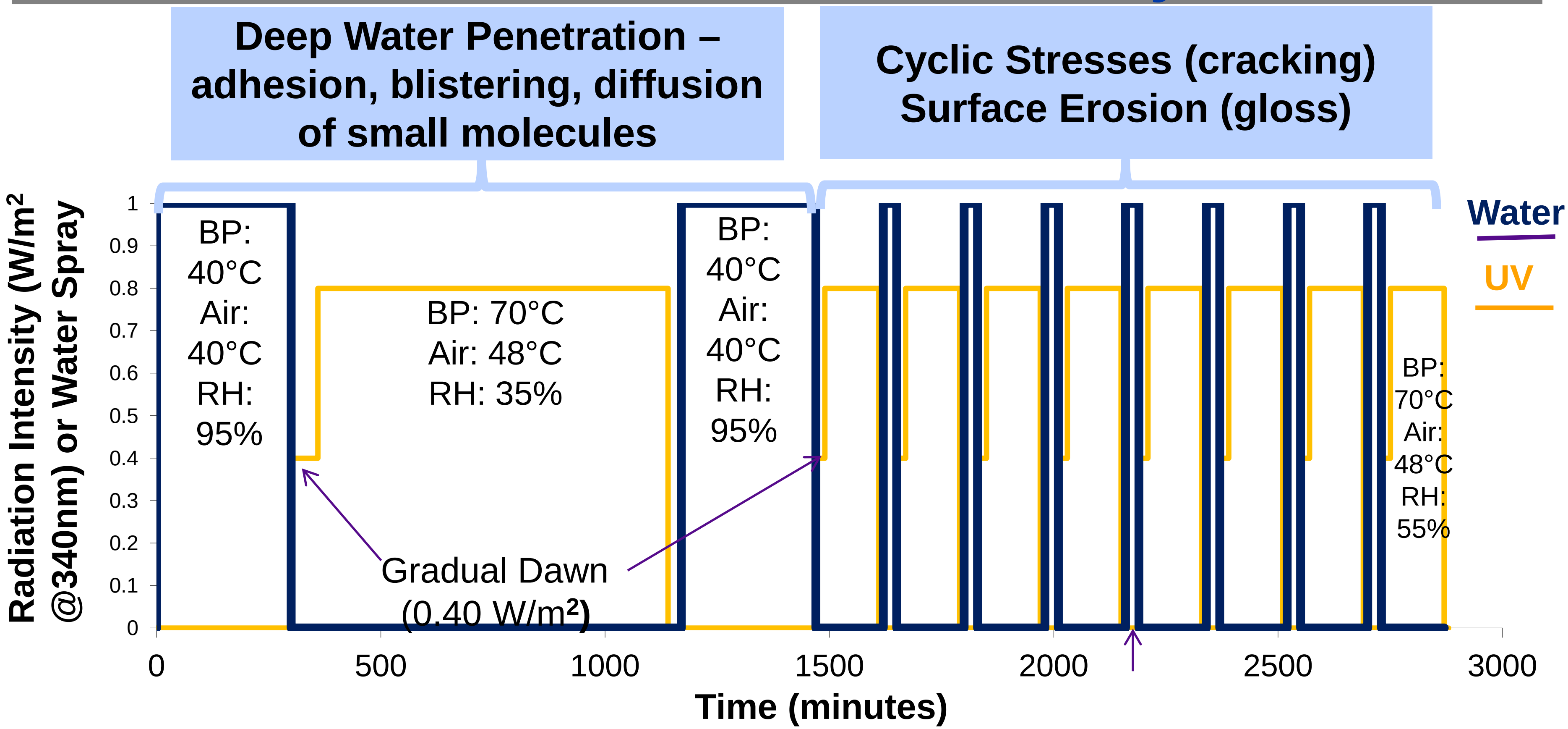
SAE J2527 Water and Irradiance Cycles



- 180 minute block
- 1 stress cycle/block
- 3.9 kJ/m^2 @ 340 nm per stress cycle
- 31.7 kJ/m2 @ 340 nm per day

Step #	Water Spray	Irradiance (W/m^2 @340 nm)	Humidity %	Air Temp (C)	Black Panel Temp (C)	Duration (minutes)
1	Off	0.55	50	47	70	40
2	On	0.55	50	47	70	20
3	Off	0.55	50	47	70	60
4	On	0	95	38	38	60

New Protocol Water and Irradiance Cycles



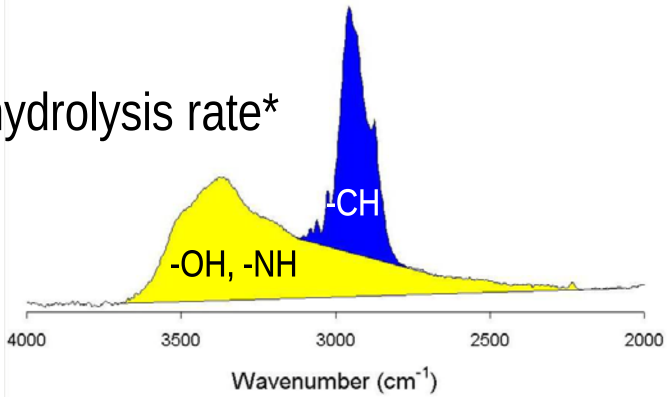
COMPARISON	New	SAE J2527	S. Florida
Max Irradiance (W/m^2 at 340 nm)	**0.80**	**0.55**	**0.65**
Avg. Relative UV Exposure/24 hrs*	**~5.2**	**~3.8**	**1.0**
Block Time (Minutes)	2880	180	1440
UV Exposure /Stress Cycle (kJ/m^2)*	**9.9**	**3.9**	**~8.4**

* Based on Florida year of 3080 kJ/m^2/nm at 340 nm

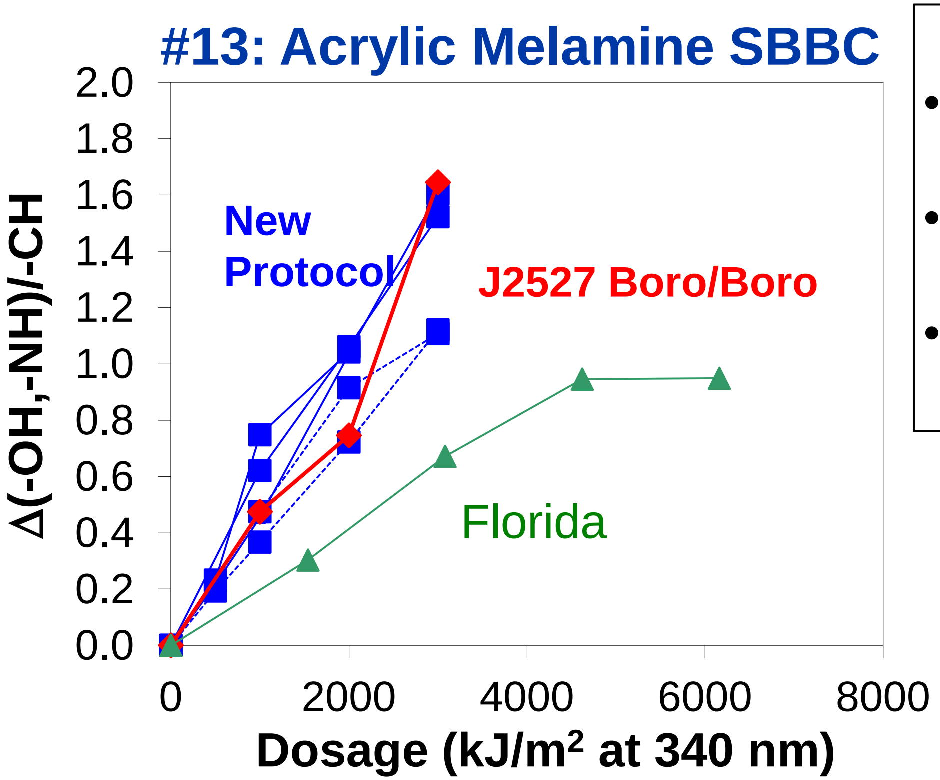
Automotive Coating Chemical Degradation

Quantification:

Use $\frac{(\text{-OH, -NH})_{area}}{\text{-CH}_{area}}$ ratio to follow relative oxidation/hydrolysis rate*



* *Gerlock et al,* Polym. Deg. and Stab., 62, 225, 1998



Sample #13:

- New Protocol or SAE J2527 slope is ~2.8 X So. Florida
- Dosage per day for New Protocol is ~5.2X So. Florida
- New Protocol Acceleration factor ~15X (SAEJ2527 acceleration factor ~ 10X)

Overall for New Protocol on 20 Samples

- Acceleration factor ~10X
- Ranged from 8X to 16X

Automotive Coating Physical Failure (#13)

CC / BC Chemistry: **Acrylic Melamine / Solvent Borne Basecoat**

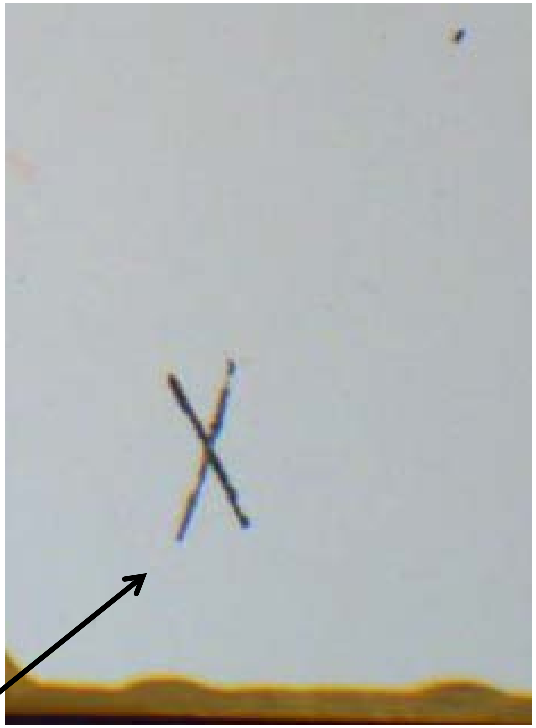
Paint System Construction: CC (no UV absorber)/BC/e-coat

Result: 2 year Florida and 3000 kJ New Protocol exposure produce partial delamination of basecoat off of electrocoat. 2527 does not.

So. Florida @ 2 year

J2527@ 3000 kJ

New Protocol @ 3000 kJ



Slight BC/E-coat pick-off on Florida and New Protocol

Automotive Coating Physical Failure (#97)

CC / BC Chemistry: 2K Polyurethane / Water Borne Basecoat

Paint System Construction: CC (no UV absorber)/BC/primer/e-coat

Result:. 2 year Florida and 3000 kJ New Protocol have blistering and delamination of CC off of BC. 3000 kJ 2527 has neither.

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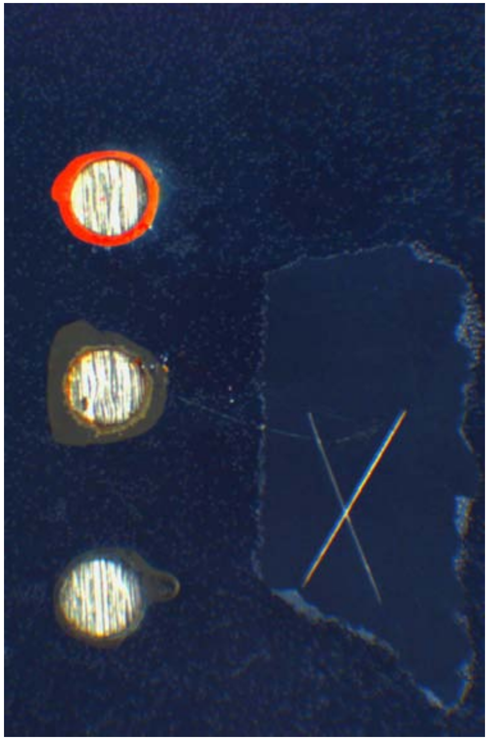
So. Florida @ 2 year



J2527@ 3000 kJ

New Protocol @ 3000 kJ

Automotive Coating Positive Control (#86)

BC / CC Chemistry: 2K Polyurethane / Water Borne Basecoat

Paint System Construction: CC/BC/primer/e-coat

Result: No Failures for any type of exposure.

.

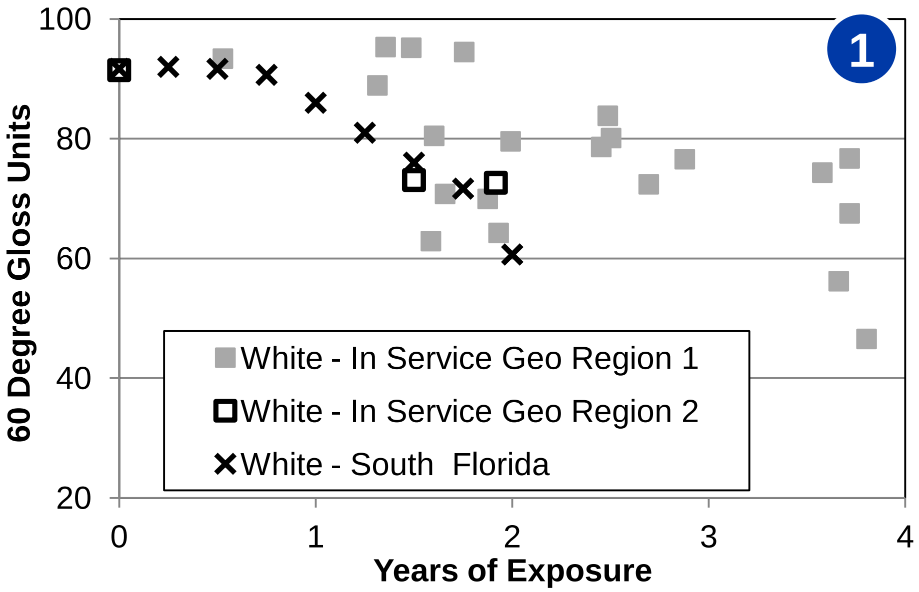
So. Florida @ 2 year

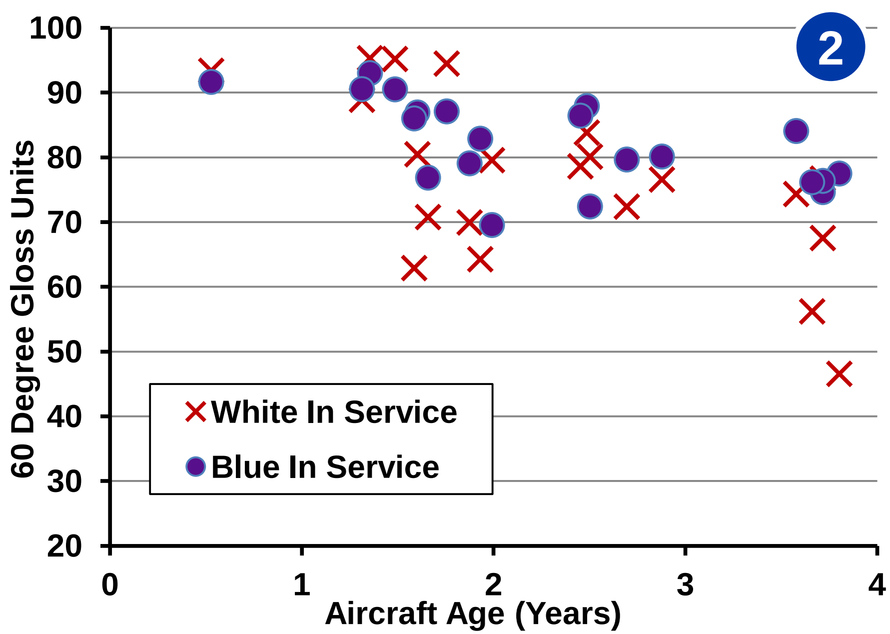
J2527@ 3000 kJ

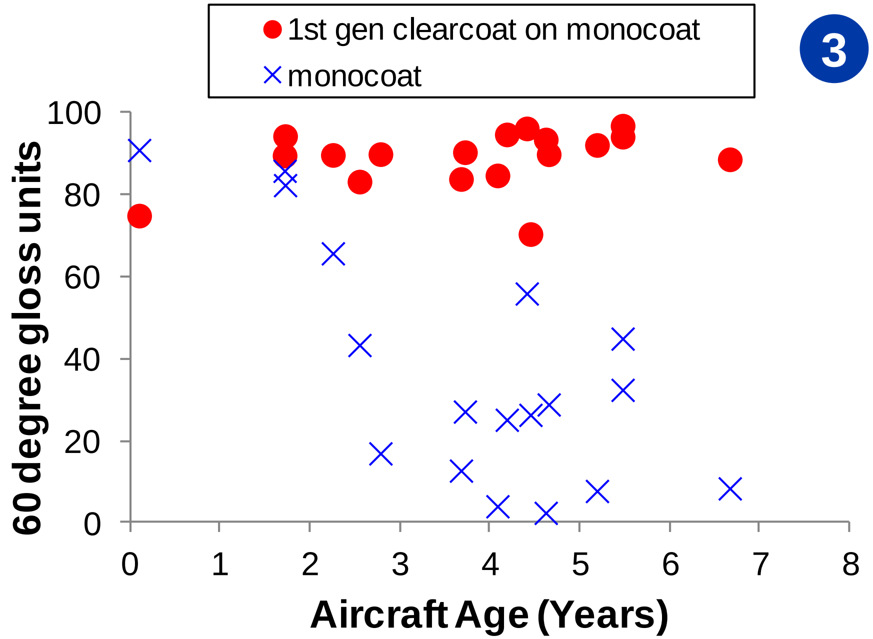
New Protocol @ 3000 kJ

Aerospace Coating Natural Weathering Gloss Degradation

1. Florida is 1X to 2X faster than in service data
2. Blue and white monocoat gloss degrade similarly in-service
3. 1st gen clearcoat/monocoat suggests BC/CC will enhance gloss retention

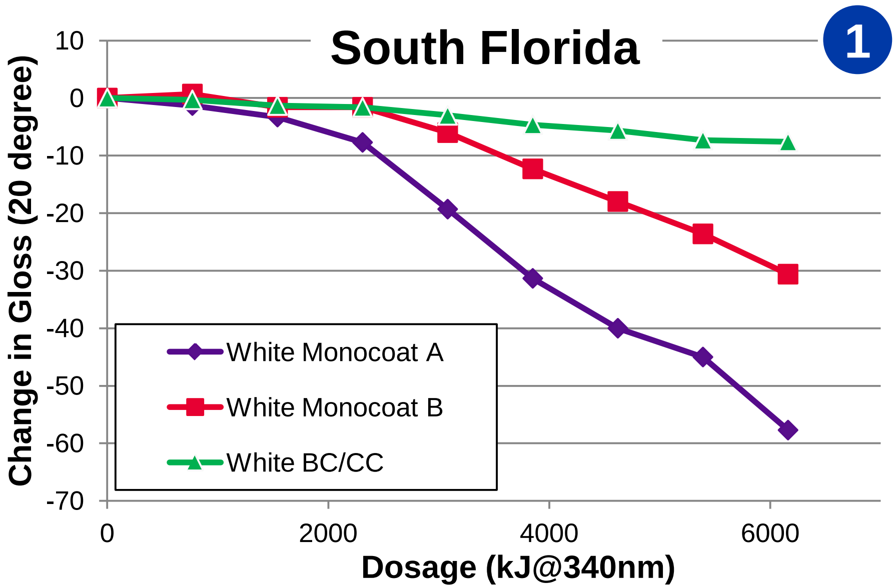


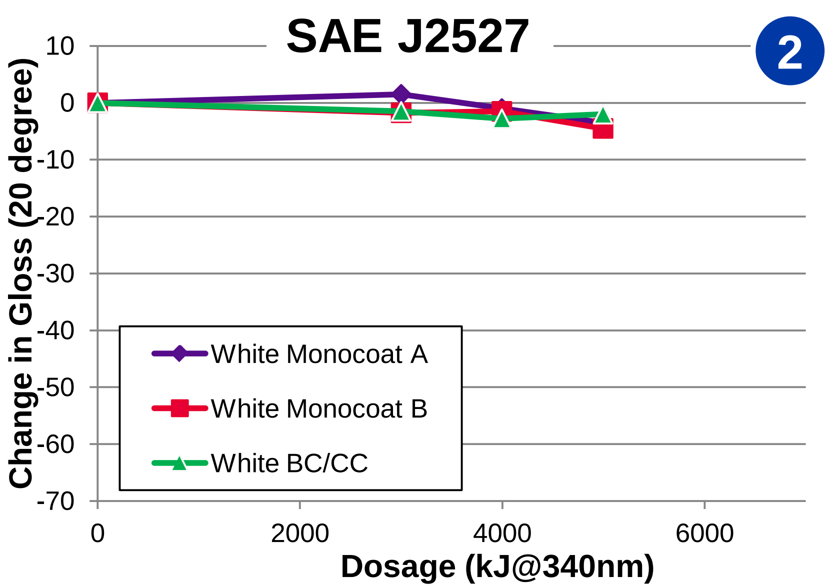


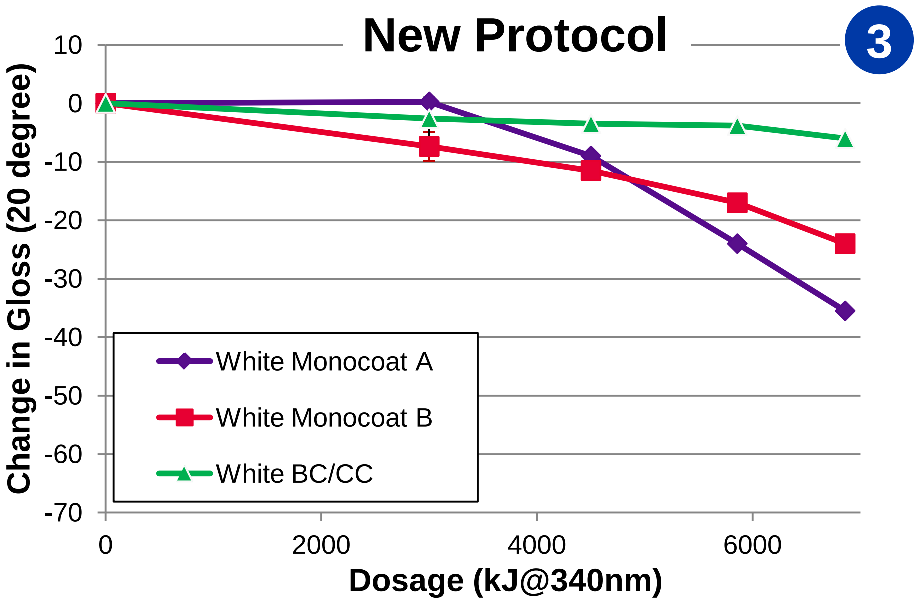


Aerospace White Coating Gloss Degradation

1. Florida white data consistent with fleet surveys/expectations
2. SAE J2527 provides no differentiation
3. New Protocol consistent with expectations at higher dosages
4. New protocol is 3-4X faster than Florida exposure

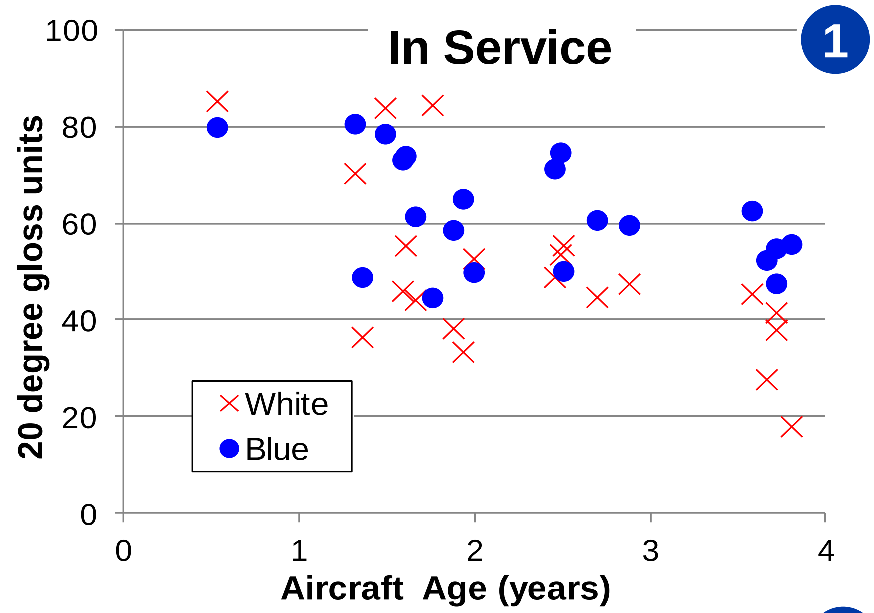


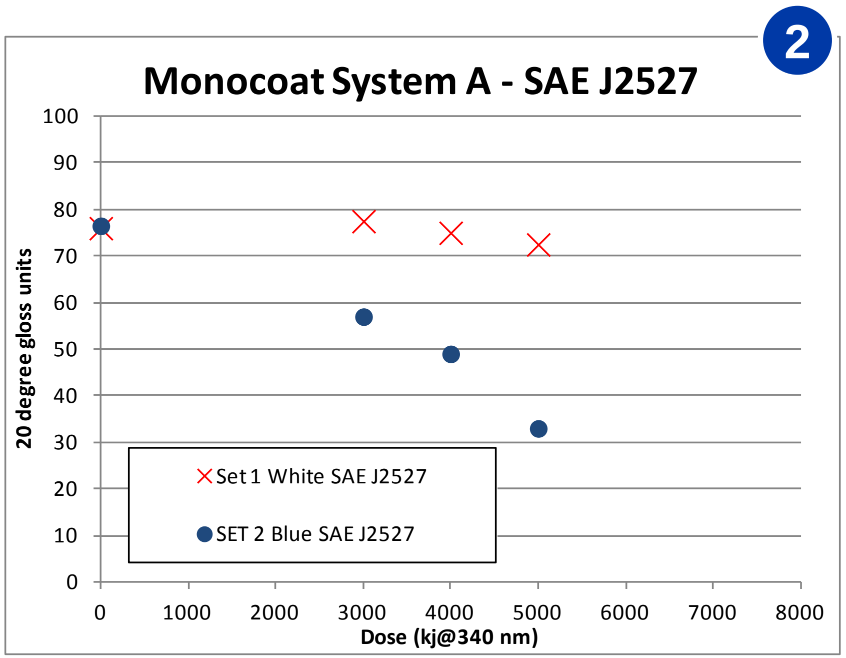


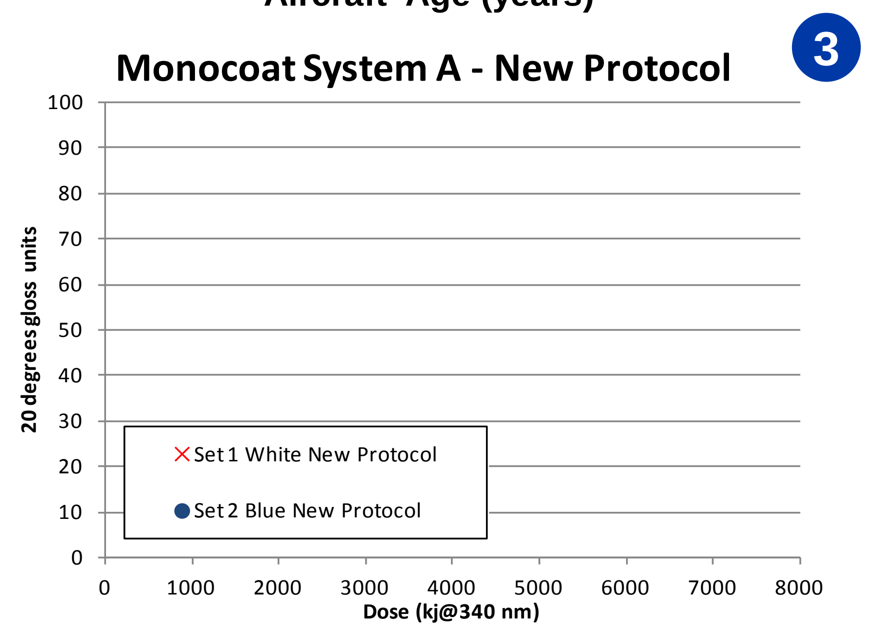


Aerospace Blue Coating Gloss Degradation

- New protocol anticipates white versus blue monocoat behavior much better than SAE J2527







Conclusion

- New light filters replicating sunlight spectral power distribution drive the correct photochemistry in exterior coating systems
- Physical failures induced by water can be replicated through the use of longer water sprays during the dark cycle augmented with numerous shorter sprays
- New Protocol correctly
  - Anticipates almost all failure modes observed in South Florida exposed coating systems (adhesion, blistering, cracking, gloss loss)*
  - Predicts "good" paint systems demonstrating no failures in Florida exposures
- For automotive BC/CC coatings, New Protocol is:
  - ~ 40% faster than SAE J2527
  - ~10X faster than South Florida
- For aerospace coatings, New Protocol is:
  - ~2X faster than SAE J2527 and ~3 to 4X faster than South Florida
  - Better predictor of gloss loss in service than SAE J2527.
  - There may be other factors particular to monocoats and/or aerospace environments that must be taken into consideration.
- Applicability and efficacy of the New Protocol depends on chemical and physical degradation pathways of the coating system.

* More details in Nichols at al, JCTR, DOI:10.1007/s11998-012-9467-x (accepted for publication

Closing Remarks

- Most of the test results shown here are the results of 8+ years of work by a consortium of Ford, Boeing, Bayer, BASF, Atlas, and Q-Lab*.
- Similar work has been conducted by Honda R&D – North America on automotive basecoat-clearcoat systems**
- The two test methodologies have been merged and tested leading to a proposed ASTM Standard Practice “Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings”

* Nichols et al, “An Improved Accelerated Weathering Protocol to Anticipate Florida Exposure Behavior of Coatings”, J. Coat. Tech. Res, accepted for publication, 2012, DOI:10.1007/s11998-012-9467-x.

** Fitz, T., "Development of an Enhanced Accelerated Weathering Test Cycle for Automotive Coatings," SAE Int. J. Mater. Manf. 5(2):2012, doi:10.4271/2012-01-1173.

Acknowledgements

- Automobile photos are used with permission from Ford
- Instrument photos are used with permission from Atlas and Q-Lab
- Airline photos are used with permission from Qantas and Boeing.
- Karen Schultz of Boeing provided the aerospace monocoat moisture absorption data