2020 Service Life Prediction of Polymers and Related Materials

March 23 - 27, 2020

Sharpening the FOCUS

Denver, CO

Q-LAB

UL

Exponent®

ATLAS MATERIAL TESTING SOLUTIONS

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Picture view of 2020 program

Time	Monday	Tuesday	Wednesday	Thursday	Friday
7:00	Breakfast				
7:30	Welcome				
8:00	Step 0	White, C	McGreer	Miller	B. Siebert
8:30	Step 1	Rosseler	Wood	Gu	Ito
9:00		Burns (WS)	Collin	Schelhas	G. Siebert
9:30	Break	Break			
10:00	Step 2	Pickett	Wallis	Hacke	Riahinezhad
10:30		Madronich	Pickett	Karl-Anders	Goodwin
11:00		Habte	Celina	Miller	Pauli
11:30		Discussion			
12:00					
12:30	Lunch				
1:00					
1:30					
2:00	Step 3	Alig	Sung	Griffin	
2:30		Ryland	Lai	Gast	
3:00		Linde	Pintar	Burns (STD)	
3:30	Break	Sharma	Break	Break	
4:00	Future	Break	Discussion	Discussion	
4:30	Discussion	Discussion			
5:00					
5:30					
6:00					
6:30	Reception	Banquet	Dinner	Poster	
7:00		Dinner	The Opera	Session	
7:30		The edge	House		

Service Life Prediction: Sharpening the Focus
March 23-27, 2020
Sheraton Downtown
Denver, Colorado

On behalf of the technical organizing committee and the sponsors from **Exponent, Atlas, UL**, **Q-Lab**, and the **National Institute of Standards and Technology**, I would like to welcome you all to ***Service Life Prediction: Sharpening the Focus.*** This conference features a strong technical program of cutting-edge research in service life prediction, including presentations from across the globe with a diverse mix of industrial, academic and government perspectives and moderated panel discussions.

The organizing committee has designed this meeting to highlight the current state of Service Life Prediction. Benchmarking the current state of the art is an important desired outcome of this meeting. Additionally, the discussion sections will focus on identifying areas where additional research is required. A key focus is understanding the barriers and opportunities for including the state-of-the-art science into industry common practice. These discussions will also be used to identify areas where additional scientific results would speed up the adoption of SLP technology.

This meeting will feature a one-day short course in service life prediction. Attendees of this short course will gain an understanding of the current and upcoming world of durability testing and service life prediction. This will enable anyone new to the field to more fully understand and participate in the rest of the meeting.

The meeting has an active social/networking component. This starts Sunday night with an informal gathering where there will be very light snacks and a cash bar. The week will start with the all-day short course on Monday and a reception Monday evening in the hotel. The meeting starts Tuesday morning, and Tuesday evening will be a dinner at Earls Kitchen + Bar a short walk from the Sheraton. Wednesday night features a dinner at Kevin Taylor's opera house. Thursday night we will have a poster session with light refreshments. The conference wraps up on Friday at noon.

Many thanks to all the authors, session chairs, organizers, and participants for making this conference possible. Wishing you all an enjoyable and productive time in Denver Colorado.

Dr. Christopher C. White
Engineering Laboratory
National Institute of Standards and Technology

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List View of 2020 Program

Short Course on Service Life Prediction

Discussion Leaders: Chris White, David Burns, James Pickett

Monday March 23.

Sheraton Downtown Denver 7:30 AM -6:30 PM.

Short Course: Full day (7 hour) workshop

Title: Introduction to Predicting In-Service Performance

Organizers: Chris White, David Burns, Jim Pickett

After attending this workshop, the participant will understand the current state of the art for durability testing of polymeric materials. The short course will follow the steps outlined for the service life prediction (SLP) process and provide useful information for durability testing ranging from QC, product development, and standards testing to fully-validated SLP methods and protocols. The limitations of current methods and needs for future work will be discussed.

Course Outline:

- **7:30-8 AM Background for SLP**
- **Step zero: 8:00-8:30 AM** What are we trying to do? (20-30 minutes)
    - Rationale for durability testing and SLP
    - Kinds of testing: QC/Spec Test to SLP
        - Trade-off between risk, costs, time
        - Competitive advantage of reliable warranties from an industry perspective
- **Situation Analysis**
- **Step 1: 8:30-9:30 AM** (60 minutes)
    - What we need to know for SLP-
        - Defining the application/in-service use environment
    - Understanding and quantifying the in-service climate
        - Benchmark outdoor exposure conditions
- Coffee Break 9:30AM -10:00 AM
- **Quantifying sensitivity to stress 10:00 AM-12:00 AM (2 hours)**
- **Step 2:** Finding the responses of a material to environmental stresses
    - General degradation pathways and kinetics,
    - Light: action spectra, reciprocity, light sources w/ experimental methods
    - Heat: use and limitations of the Arrhenius equation and activation energies w/ experimental methods
    - Water: complexity of rain, humidity, condensation, ice; chemical and mechanical w/ experimental methods
    - Mechanical stress and strain w/ experimental methods
    - Interactions

- Lunch 12:00- 2:00 PM (2 hours)
- **Creating a model**

- **Step 3:** 2:00- 3:30 PM **Making predictions** (1.5 hours)
  - SLP modeling techniques and when to use them
  - Full SLP Modeling: analytical, statistical, and cumulative damage models
    - Hazards of extrapolation – stay within experimental design
    - Interaction parameters
    - Incorporation of process parameters not just target processes
    - Modeling degradation versus SLP
  - Product/Materials Specific Predictive testing –
    - Environmental simulation testing: improved and customized methods
    - Experimental methods
  - Validation
- **Coffee Break 2:30-3:00**
- **Future directions 4:00 -4:30 (30 minutes)**
  - Risk assessment with SLP: failure and liability
  - Standards: dealing with current ones and drafting new ones
  - Approaches to generate new knowledge
- **Discussion 4:30-6:00 (1.5 hours)**
  - **Sponsor talks (15-20 minutes each)**
    - **Atlas**
    - **Q-lab**
    - **Exponent**
    - **Lab Sphere**

Wrap up 6:00-6:30 PM

Reception

Time	Title
6:30 PM- 8:00 PM	Reception

Table View of SLP Program

Tuesday Morning: General Overview of Service Life Prediction and Solar Irradiance data.

Discussion Leaders: Carlos Juarez, Jessica Vargas, Hom Sharma

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
8:00 AM-8:30 AM	Chris White	Introduction, Overview. ?
8:30 AM-9:00 AM	Olivier Rosseler	A proposed Service Life Prediction framework, to improve upon
9:00 AM-9:30 AM	David Burns	A Weathering Science approach to Service Life Prediction
9:30 AM-10:00 AM	Coffee Break	
10:00 AM-10:30 AM	Jim Pickett	Annual solar spectral energy distributions from spectroradiometer data
10:30 AM-11:00 AM	Saha Madronich	The Tropospheric Ultraviolet-Visible (TUV) Model
11:00 AM-11:30 AM	Aron Habte	Best Practices in Acquiring Measured and Modelled Solar Irradiance Data
11:30 AM-12:30 PM		Panel Discussion
12:30 PM-2:00 PM	LUNCH	

Tuesday Afternoon: Service Life Prediction, Specific Issues.

Discussion Leaders: Graham Duthie, Michael Dimitriou, Stephen Fisher

Time	Presenter	Title
2:00 PM-2:30 PM	Ingo Alig	Modelling of water uptake and mechanical stresses of thermoplastic polymers: Comparison of natural weathering and accelerated weathering protocols
2:30 PM-3:00 PM	Brad Ryland	Machine Settings vs. Material Stresses: Measuring and Modeling Water Concentration in Accelerated Weathering
3:00 PM-3:30 PM	Erik Linde	Development of a Diffusion-Limited Hydrolysis Model
3:30:PM-4:00 PM	Hom Sharma	Moisture Sorption and diffusion by 3D printable polymeric materials
4:00PM-4:30 PM		Break
4:30 PM-6:30 PM		Discussion

Dinner. Earl’s on Top, a short walk from the Sheraton.

Nestled in the heart of Downtown Denver, our venue offers a bright and modern setting, perfectly accented with rich woods and eclectic lighting inspired by Colorado’s rustic landscape. Enjoy our fresh, modern fare punctuated with global flavors, handcrafted cocktails, a comprehensive wine collection and approachable, professional service.

The Earls On Top venue features four unique spaces that can be booked individually or together as one. Our large private Banquet Room that fits groups of up to 65 people for seated dinners or private receptions are versatile and can be used for any style event. Our large all-seasons Patio looks out onto the 16th Street promenade, with a perfect view of Denver, and is perfect for a reception style event.

https://earls.ca/locations/glenarm/menu/kitchen

Wednesday Morning: Factors affecting Degradation.

Discussion Leaders: Chris Wallis, David Miller, Lawrence Durante

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
8:00 AM-8:30 AM	Matt McGreer	Influencing Factors Affecting the Reproducibility of Weathering Tests
8:30 AM-9:00 AM	Kurt Wood	Evaluation of the ASTM D7869-13 test method to predict the gloss and color retention of premium architectural finishes-II
9:00 AM-9:30 AM	Steeve Collin	Assessment of polymer durability by accelerated photo-ageing experiments
9:30 AM-10:00 AM	Coffee Break	
10:00 AM-10:30 AM	Christopher Wallis	Degradation of Plastic Waste
10:30 AM-11:00 AM	Jim Pickett	Weathering Acceleration Factors for Aromatic Polymers: Implications for Testing
11:00 AM-11:30 AM	Mathew Celina	Quantification of 'Carbonyls' via IR Spectroscopy – A Broader Perspective
11:30 AM-12:30 PM		Panel Discussion
12:30 PM-2:00 PM	LUNCH	

Wednesday Afternoon: Modeling.

Discussion Leaders: Andy Francis, Karl-Anders Weiss, Matt McGreer

Time	Presenter	Title
2:00 PM-2:30 PM	LiPiin Sung	Service life prediction for thermoplastics using multiple material properties from accelerated and outdoor weathering
2:30 PM-3:00 PM	Yuming Lai	Characterizations of structure and property changes of high density polyethylene after accelerated UV
3:00 PM-3:30 PM	Adam Pintar	Multivariate Statistical Models for Service Life Prediction of Polymers
3:30:PM-4:00 PM		Break
4:00PM-6:30 PM		Discussion

Banquet Dinner:

KEVIN TAYLOR'S AT THE OPERA HOUSE

14TH & CURTIS STREETS *in the Denver Performing Arts Complex lower level of the Ellie Caulkins Opera House* DENVER, CO 80202

Located in the Chambers Grant Salon in the Ellie Caulkins Opera House at the Denver Performing Arts Complex, Kevin Taylor's at the Opera House serves pre-theater cocktails and dinner on evenings with performances in the Ellie Caulkins Opera House, Buell Theater and/or Boettcher Concert Hall.

Also, for private events, Kevin Taylor Catering serves all of the unique spaces within the Opera House. These include the new, sophisticated, exposed-brick 8,000 sq. ft. Studio Loft space, as well as the Chambers-Grant Salon, an extraordinary 11,600 sq. ft. space featuring twinkling fiber optic ceilings, exposed stone walls, full stage and luxurious finishes. (303) 640-1012.

About KT: In 1987, at the age of 25, self-taught chef and Denver native Kevin Taylor opened Zenith American Grill, serving his unique take on southwestern cuisine. Six months after opening, Zenith was among the three top-rated restaurants in Denver. Awards and recognition were garnered from local press and more than 25 national media outlets, including Bon Appetit, Restaurant Hospitality and GQ. Zenith also earned a prized four-star rating, securing Taylor's place on the culinary map.

Since then, Taylor has opened many successful restaurants, all appealing to those with a sophisticated palette, as well as a love for the arts. Although each restaurant's menu and style offers diners a singular experience, Taylor's belief in fresh ingredients and beautiful presentation is a common thread throughout all.

"When I cook, the first and foremost thought in my mind is that each guest needs to be wowed," says Taylor. "I take perfection seriously and am constantly looking for ways to improve myself as a chef, the food, the ambiance and setting, and how people feel when they dine in any of our restaurants. Food is just a portion of the overall guest experience; I often ask myself how contemporary cuisine can be better, and go from there."

https://www.ktrg.net/kevin-taylors-at-the-opera-house/

Thursday Morning: Photovoltaics

Discussion Leaders: Brad Ryland, Peter Hacke, Kurt Wood

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
8:00 AM-8:30 AM	David Miller	Degradation in Photovoltaic Encapsulation Strength of Attachment: Results of the First PVQAT TG5 Artificial Weathering Study
8:30 AM-9:00 AM	Xiahong Gu	Development of Methodology for Service Life Prediction of PV Backsheets
9:00 AM-9:30 AM	Laura T. Schelhas	Understanding PV Polymer Backsheet Degradation through X-ray Scattering
9:30 AM-10:00 AM	Coffee Break	
10:00 AM-10:30 AM	Peter Hacke	Combined-accelerated stress testing (C-AST) for service life prediction of PV modules
10:30 AM-11:00 AM	Karl-Anders Weiß	PV modelling
11:00 AM-11:30 AM	David Miller	Round-Robin Verification of Specimen Temperature During Accelerated Testing for the PVQAT TG5 Studies
11:30 AM-12:30 PM		Panel Discussion
12:30 PM-2:00 PM	LUNCH	

Thursday Afternoon: Standards.

Discussion Leaders: Mat Celina, Michael Owen-Bellini, Laura Schelhas

Time	Presenter	Title
2:00 PM-2:30 PM		Start at 2:30
2:30 PM-3:00 PM	Anthony Griffin	Failure from the Start: Evolutionary Design of Polymeric Materials using Predicted Service Life Data as a Design Trait
3:00 PM-3:30 PM	Florian Gast	Testing artificially aged silicone sealants for advanced applications
3:30:PM-4:00 PM	David Burns	The Role of Industry Standards in Service Life Prediction
4:00PM-4:30 PM		Break
4:30 PM-6:30 PM		Discussion SLP standards and implementation.

Thursday night: Posters at the Hotel.

Presenter	Title
Christopher Wallis and Celine Moreira	Designed environmental interactions of biodegradable plastics with air, light and moisture: Correlating novel laboratory weathering methodologies with natural exposure.
David Burns and Jim Pickett	Applying SLP to Industrial R&D: Material-appropriate accelerated weathering
Michael Owen-Bellini	Validating Advanced Stress Testing Protocols Using Analysis of Degraded Polyvinylidene Fluoride-Based Backsheet Films
Olga Kuvshinnikova* and James E. Pickett	Is ASTM D7869 Accelerated Weathering More Predictive Than ISO4892-2 for Uncoated Plastics?
James E. Pickett	How the Relative Photodegradation Rates of Polymers Depend on the UV Source

Friday Morning: Mechanical strain.

Discussion Leaders: David Goodwin, Chris White, Barbara Siebert

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
8:00 AM-8:30 AM	Barbara Siebert	Influences on the service life of silicones in the edge seal of insulating glass units
8:30 AM-9:00 AM	Masayuki Ito	Temperature dependence of radiation induced degradation of chlorosulfonyl polyethylene and chloroprene elastomer
9:00 AM-9:30 AM	Geralt Siebert	Creeping behaviour of PVB under different temperatures and humidity
9:30 AM-10:00 AM		
10:00 AM-10:30 AM	Marzieh Riahinezhad	Investigation onto the durability and service life prediction of silicone membrane in construction applications
10:30 AM-11:00 AM	David Goodwin	Methods to assess polymer composite degradation in civil infrastructure applications
11:00 AM-11:30 AM	Alexander Pauli	Investigation of the mechanical behaviour of PVB interlayers due to UV ageing in the context of large-scale testing
11:30 AM-12:00 PM		Panel Discussion
12:00 AM-1:00 PM		
1:00 PM-2:30 PM		Wrap up Items.

Tuesday Morning: General Overview of Service Life Prediction and Solar Irradiance data.

The Tuesday morning session is a general overview of service life prediction, science and practices. In this section the talks will present the general state of service life prediction from many different perspectives. By the end of this session we all should be able to understand in broad terms the challenges and opportunities associated with predicting the in-service performance of polymers and other important objects when exposed to outdoor weathering. The talks after the break are focused around Ultra Violet Radiation measurement and prediction. .

Discussion Leaders: Carlos Juarez, Jessica Vargas, Hom Sharma

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
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A proposed Service Life Prediction framework, to improve upon

Oliver Rosseler, Saint-Gobain Research North America

Abstract

Our quest to answer the most common question in aging ("How long should I run thisaccelerated test to reproduce 1 year of aging?") is far from over. Several research groups have successfully applied acceleration shift factors to extrapolate the service life prediction of their materials from accelerated laboratory weathering data.

Borrowing from examples in the literature and augmented by original research data, this presentation will start to outline a generalized framework to determine the acceleration rate in laboratory weathering. Ultimately, this comprehensive procedure would enable R&D engineers to establish service life prediction with more confidence.

Ideally, this presentation will serve as a starting point for SLP specialists to build on and to identify the limits of applicability of the proposed framework.

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A Weathering Science approach to Service Life Prediction

David M. Burns

Abstract

Abstract description (500 words or less): This presentation presents an overview of the weathering science approach to service life prediction and outlines its application for robust product development and determination of commercial durability risk. The fundamental objective of all durability evaluations in an industrial context is service life prediction: How long will this product or material survive in the application and service environment(s)? Durability has significant commercial value in many industrial markets. Automotive, solar energy, architectural and marine coatings, building materials and traffic safety are examples of industries where users are willing to pay more for products with greater durability. Products that maintain their performance for years even in extreme climates are not only desired, but also required in multiple markets. Durability clearly has economic value to the end user in terms of reduced maintenance costs, extended life cycle and overall confidence in product performance. However, obtaining these benefits within a reasonable time depends on manufacturers' ability to accelerate commercialization by more rapidly assessing durability during product development, establishing product robustness and performance expectations in the shortest amount of time and finally validating marketplace durability claims. Faster to market while managing service life 'risk' is key to both product development and commercial success. Arriving at a practical low risk estimate of service life in a short (i.e., highly accelerated) time frame is a task that cannot be accomplished simply by following the standard industrial protocols. The main objective of such standards is to provide simplified quality assurance procedures for setting minimum criteria for initial sale into an application between buyer and seller. As such they are poor predictors of the functional in-service lifetime of products. Today, products are sold on a global scale requiring successful products to be durable in a wide range of climates and weather conditions. Standard industry weathering tests are extremely poor indicators of durability in multiple locations or climates. In order to predict service life with a high level of certainty product developers, manufacturers and the end consumers must move beyond being users of weathering technology and become practitioners of weathering science. Weathering technology, comprising the artificial weathering apparatus and exposure protocols in industry standards, are only tools for conducting experiments. Decades of research and practical industrial experience have shown the most dependable approach to determine the durability limitations of a construction is to fully characterize its properties and their response to applied stress. Full characterization is sound science, and sound engineering. This is the standard methodology used in all material engineering fields – and it applies equally to weathering. Weathering science is the interdisciplinary field focused on understanding the functional properties of products and the relationships between property changes, degradation process and pathways, and the stresses experienced in the in-service environment. It draws on and applies the expertise and knowledge from a wide range of fields including psychophysics, photochemistry, materials and chemical engineering, kinetics, data science and climatology to construct models to calculate time-to-failure for real world in-service locations.

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Annual solar spectral energy distributions from spectroradiometer data

James E Pickett*, Consultant, Schenectady, NY
Patrick J. Neale, Smithsonian Environmental Research Center, Edgewater, MD
Jacob P. Pickett, North Carolina State University, Raleigh, NC

Abstract:

Predicting outdoor service life of polymers and coatings requires knowledge of the spectral power distribution (SPD) of the sunlight and the annual radiant energy. Standard SPDs of sunlight are available, such as ASTM G173 and ASTM G177, but these are snapshots of the SPD at a single moment, and actual annual average spectral energy distributions (SED) have not been published for any location. The SED is the energy received at each wavelength over the course of a year. In addition, the variability of the SEDs are not known. A Smithsonian/NIST collaboration placed SR-18 UV spectroradiometers in Miami, FL, Phoenix, AZ, and Madison, WI during the period 1997-2012, collecting data at ~ 2 nm intervals between 290 and 324 nm. Similar data has been collected at Edgewater, MD for many years. The data are not complete for any year, but gaps could be patched using data from other years. This dataset was compared to data available on-line from ongoing USDA/Colorado State University outdoor spectroradiometer measurements, after similar patching. The USDA data have fewer points in the UV but extend into the visible portion of the spectrum. The data sets give consistent results and show that the SEDs can be fit using SPDs calculated using SMARTS 2.9.5 and satellite ozone data. The annual standard deviation is 4-5% for wavelengths > 300 nm. These SEDs provide benchmarks for average annual radiant energy received by horizontal and 45° south exposures near Miami and Phoenix. The methodology can be extended to the 30 locations throughout North America with long-term USDA/CSU data.

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The Tropospheric Ultraviolet-Visible (TUV) Model

Sasha Madronich, National Center for Atmospheric Research

Abstract

Knowledge of visible and ultraviolet (UV) radiation in the Earth's atmosphere and surface is fundamental to several disciplines, such as atmospheric photo-chemistry, surface photo-biology, and material photo-degradation. Direct measurements of visible and UV radiation are preferable in principle, but can be expensive (esp. if spectrally resolved), subject to considerable instrumental errors, and cannot inform future scenarios, e.g., response to changes in ozone, aerosols, or clouds. Numerical models, such as the Tropospheric Ultraviolet-Visible (TUV) model, allow rapid estimation by modeling the propagation of solar spectral radiation through the atmosphere, for user-specified input conditions of location, time, and vertical profiles of key atmospheric optical constituents (O_2, O_3, NO_2, SO_2, aerosols, and clouds). For each wavelength of interest, the TUV model solves the radiative transfer equation within a multi-layer atmosphere, including attenuation of the direct solar beam as well as the contributions of down-welling and up-welling diffuse (scattered) radiation. The model is based largely on fundamental physical principles of spectroscopy and radiative transfer, rather than empirical parameterizations, and is therefore expected to retain validity over a wide range of current and future conditions.

The TUV model code is written in FORTRAN and is freely available to the community[1]. Customization of the code is straightforward, e.g., to enable multiple calculations (loops), sensitivity studies, etc. Also, a web-based "quick TUV" calculator[2] provides sample outputs (spectral irradiances, spectral fluence rates, and band integrals) for a few user-selected inputs (spectral resolution, time and location, simple profiles of ozone, cloud, and aerosols). I will present a brief overview of the model capabilities, limitations, evaluations with observations, and a few typical applications.

[1]www2.acom.ucar.edu/modeling/tuv-download

[2]cprm.acom.ucar.edu/Models/TUV/Interactive

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Best Practices in Acquiring Measured and Modeled Solar Irradiance Data

Aron Habte and Manajit Sengupta, National Renewable Energy Laboratory

Abstract:

The National Renewable Energy Laboratory (NREL) is internationally recognized for its expertise in solar resource measurement and modeling. This is a result of significant investments by the US Department of Energy (DOE) to develop unique world-class capabilities in these areas. Developments in solar resource directly impacts the outcomes of other research and development projects supported by the DOE Solar Energy Technology Office (SETO) including PV performance and characterization, performance and economic models, and grid integration analyses. Accurate solar resource data that follows best practices are essential for reducing technical and non-technical barriers to achieving high penetration of solar energy conversion systems.

NREL's Solar Resource Research Laboratory (SRRL) is a unique world-class research facility that serves as a living laboratory for solar resource measurement and calibration R&D, characterization of solar conversion technologies, and the development of standards and best practices for dissemination. SRRL is one of the few sources of high-quality long-term solar radiation datasets in the nation and probably the only source of a complete set of measurements for solar radiation modeling research. This includes the development and testing of industry standard models such as the Simple Model of Atmospheric Radiative Transfer of Sunshine (SMARTS) and the testing of NREL Fast All-sky Radiation Model (FARMS). Furthermore, NREL has been implementing strict protocols for calibration, measurement, modeling, operation and maintenance, and assessing data quality and control of solar resource datasets. The presentation will cover the data quality assessment method employed by NREL for both measured and modeled solar resource data. The presentation will also cover, the development of a UV model to estimate the global UV irradiance contained in multiple wavebands (280–400 nm and 295–385 nm) using the total broadband solar irradiance, as measured or modeled. The method is based on simulations of both UV and total solar obtained with the SMARTS clear-sky spectral radiation model

National Renewable Energy Laboratory, Golden, CO, 80401, United States.
Email: aron.habte@nrel.gov

Tuesday Afternoon: Service Life Prediction, Water and Diffusion.

Water is everywhere. Water on the surface, water uptake, and water diffusion into materials can lead to undesirable material property changes over time that need to be accounted for when developing models to determine the service life of a product. This session will explore the latest methods for understanding and modeling how the presence of water affects our materials.

Discussion Leaders: Graham Duthie, Michael Dimitriou, Stephen Fisher

Time	Presenter	Title
2:00 PM- 2:30 PM	Ingo Alig	Modelling of water uptake and mechanical stresses of thermoplastic polymers: Comparison of natural weathering and accelerated weathering protocols
2:30 PM- 3:00 PM	Brad Ryland	Machine Settings vs. Material Stresses: Measuring and Modeling Water Concentration in Accelerated Weathering
3:00 PM- 3:30 PM	Erik Linde	Development of a Diffusion-Limited Hydrolysis Model
3:30:PM- 4:00 PM	Hom Sharma	Moisture Sorption and diffusion by 3D printable polymeric materials
4:00PM- 4:30 PM		Break
4:30 PM- 6:30 PM		Discussion

Modeling of water uptake and mechanical stresses of thermoplastic polymers: Comparison of natural weathering and accelerated weathering protocols

Ingo Alig, Alexander Neumann, Harald Oehler, Dirk Lellinger, and Andreas Bülow

Abstract: The conformance between performance of polymeric materials tested after long-term outdoor exposure and those exposed to a series of elevated stresses in laboratory testing is often not satisfying. To improve the correlation between outdoor weathering and accelerated weathering protocols for polymeric materials, extensive research has been performed in the last decades (see [1, 2] and references).

For development of improved laboratory weathering protocols, simulations of material characteristics such as water uptake or internal stresses can be helpful. The simulations can mimic both, the exposure of defined series of elevated environmental stresses (accelerated weathering protocols) and outdoor data for a given geographic position (natural weathering). Based on a material model for the polymer, property changes for the different series can be simulated. The results for different protocols and for outdoor data can be compared to identify the most suitable laboratory weathering protocol.

Outdoor weathering tests are often performed under such climatic conditions (e.g. for Florida or Arizona), which are judged to be more extreme than most in-service environments. However, even for near real time outdoor exposure this approach will not yield a validated prediction for the performance in an arbitrary outdoor environment [2]. Since time-resolved outdoor weather data are nowadays accessible for many geographic positions and often for periods of many years, it becomes possible to simulate long-term performance of a given material for in-service environments of interest. Although there are limitations due to the material models and its parametrization, this approach provides input for development of improved accelerated weathering protocols for specific geographic positions. In addition to the development of accelerated weathering protocols for material development, service life prediction of polymeric materials and assemblies can be improved.

First results of numerical simulations of water uptake (sorption profiles) and mechanical stresses of polymeric materials (e.g. PMMA) exposed to natural weathering for several years in Florida and Stuttgart in Germany are presented. The simulations using outdoor data are compared to those for accelerated weathering protocols such as ASTM D7869 or SAE J2527. As far as possible, the results of the simulations are compared with experimental results from natural and accelerating weathering using the same protocols. Finally, the possibilities and limits for the "design" of accelerated weathering protocols are discussed.

[1] M. Nichols et al., An improved accelerated weathering protocol to anticipate Florida exposure behavior of coatings, J. Coat. Technol. Res., 10 (2013) 153–173.

[2] C.C. White, L. P. Sung, H.C. Hsueh, A. Pintar, D.L. Huston, Validating predictive models with outdoor data, Natural and Artificial Aging of Polymers, T. Reichert (Ed.), 9th European Weathering Symposium, 18th – 20th September 2019, Basel, Switzerland, CEEES Publication No. 19, 2019, p. 207-219.

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Machine Settings vs. Material Stresses: Measuring and Modeling Water Concentration in Accelerated Weathering

Brad Ryland* and Bryce Williams, 3M Weathering Research Center

Abstract:

Kinetic modeling of polymer degradation in weathering studies requires knowledge of key system parameters, such as irradiance and temperature in order to properly characterize the system. Water, present as vapor (humidity) or liquid (spray, dew, etc.) has frequently been shown to have a strong influence on service life of polymers. Traditional methods of parametrizing the water stressor, like time of wetness (TOW) and chamber relative humidity are useful and easy to set/measure in a weathering device, but they do not necessarily reflect the concentration of water within the polymer matrix nor the stress associated with hydration/dehydration. This talk will outline an approach used to measure the kinetics of water uptake into polymer films during various accelerated weathering cycles. Polymer composition, the existence of spray phase, and how local sample temperature can affect both the rate and equilibrium concentration of water during weathering. Through this materials-level knowledge, more accurate physical models can be used to explain and predict polymer behavior.

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Development of a Diffusion-Limited Hydrolysis Model

Erik Linde, Nicholas Giron, Mathew Mathew Celina , Sandia National Laboratory

Abstract Title:

Polymer degradation under diffusion-limited oxidation (DLO) conditions is very well established and is easily applied in predictive models for spatially dependent degradation processes from 1D to 3D. In contrast, diffusion-limited hydrolysis (DLH) has not been fully defined even though it is an important mechanism for aging of polymeric materials where water diffusion competes with hydrolytic reaction pathways. For a meaningful model, several parameters need to be experimentally determined: Water uptake, water diffusivity, and hydrolysis reaction rates to establish reaction kinetics. Further, these parameters must be obtained as a function of relative humidity and temperature to enable a broader predictive framework. In this presentation, we will explore the similarities and differences between DLO and DLH, present experimental results for a polyurethane foam material, and show strategies for the definition of a predictive aging model. Some predictions for specific environments and geometries with the newly developed model will serve as examples.

Key words: Diffusion-limited hydrolysis, predictive models, water diffusion, water uptake

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Moisture Sorption and diffusion by 3D printable polymeric materials

Hom N. Sharma, Yunwei Sun, and Elizabeth A.* Glascoe

Lawrence Livermore National Laboratory

Abstract :
Dynamic sorption and diffusion of moisture in polymeric materials is important due to their use in many products we use daily, including electronic devices, pharmaceuticals, food packaging, medical devices, and automotive parts. Moisture interactions with polymeric materials may cause undesirable changes to their mechanical properties, chemical compatibility, and durability that may ultimately result in failure of the part or product. The sorption diffusion process is dynamic and consists of different sorption modes and varies dramatically in different materials. Therefore, a detailed understating of the moisture uptake and diffusion is crucial.

In this study, we investigate the moisture sorption and diffusion phenomena using a combined experimental and modeling approach. A 3D printable siloxane polymer (synthesized using 3D printing and compression molding techniques) with hydrophobic surface treated Aerosil R8200 filler is used for a detailed sorption diffusion study. A wide range of temperatures and relative humidities (RH) are considered to quantify the moisture transport mechanism. Gravimetric type dynamic vapor sorption (DVS) experiments were employed to measure the moisture uptake and used for the modeling. A reactive transport model is used which includes a triple-mode (Henry, Langmuir and pooling) sorption model and chemical reaction kinetics. Results show that the surface-treated silica filler greatly influences the moisture uptake mechanism and total moisture uptake in 3D printed and compression molded polymers. Our model accurately captures experimental moisture sorption profiles with specific sorption mode contributions. Moisture sorption behavior from siloxane silicones with untreated silica (fumed silica) fillers will be compared to this custom 3D printable siloxane material.

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Dinner. EDGE Restaurant & Bar, 1111 14th Street 303.389.3050

Located inside Four Seasons Hotel Denver, EDGE Restaurant & Bar is a progressive American Steakhouse and home to a dynamic see-and-be-seen bar. A progressive American steakhouse with global influences, EDGE Restaurant is led by Executive Chef Simon Purvis, who infuses passion and creativity into every dining experience. EDGE Restaurant utilizes superior quality meats, locally sourced Colorado game, fresh seafood, and produce from nearby farms to cultivate dishes full of seasonal flavors. The knowledgeable team, masters of their trade, graciously provide intuitive service throughout the contemporary restaurant which features subtle reflections of Colorado's natural beauty.

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https://www.edgerestaurantdenver.com/

Wednesday Morning: Factors affecting Degradation.

Previous sessions have examined individual weathering stresses, such as UV or moisture. This session works to understand how to understand when more than one environmental stressor is present. For example, in outdoor weathering, all weathering stressors are present. How to the current standards, test methods preform when more than one environmental stressor is present?

Discussion Leaders: Chris Wallis, David Miller, Lawrence Durante

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
8:00 AM-8:30 AM	Matt McGreer	Influencing Factors Affecting the Reproducibility of Weathering Tests
8:30 AM-9:00 AM	Kurt Wood	Evaluation of the ASTM D7869-13 test method to predict the gloss and color retention of premium architectural finishes-II
9:00 AM-9:30 AM	Steeve Collin	Assessment of polymer durability by accelerated photo-ageing experiments
9:30 AM-10:00 AM	Coffee Break	
10:00 AM-10:30 AM	Christopher Wallis	Degradation of Plastic Waste
10:30 AM-11:00 AM	Jim Pickett	Weathering Acceleration Factors for Aromatic Polymers: Implications for Testing
11:00 AM-11:30 AM	Mathew Celina	Quantification of 'Carbonyls' via IR Spectroscopy – A Broader Perspective
11:30 AM-12:30 PM		Panel Discussion
12:30 PM-2:00 PM	LUNCH	

Influencing Factors Affecting the Reproducibility of Weathering Tests

Matt McGreer, Dr. Florian Feil

Atlas Material Testing Technology GmbH, Germany

In natural and in artificial weathering the specimen surface temperature might not only influence the reaction speed, but also the degradation pathway. Therefore, representative and reproducible surface temperatures are essential for consistent, realistic test results and for service life prediction studies.

Most test methods, according to common weathering standards like ASTM G155, require control of an uninsulated or insulated black panel, referred to as the BPT or BST, respectively. BPT and BPT are reference temperatures and intended to be close to the maximum specimen temperature under irradiation. Some standards like ISO 4892-2 or ISO 16474-2 require also ambient air or chamber temperature control. Even if those factors are controlled, specimen surface temperatures might vary from instrument to instrument or from test setup to test setup. Those differences are often systematic and arise from instrument design, but also can be caused by other parameters such as laboratory conditions and lamp and filter age.

Other parameters, like specimen specific time of wetness are also influenced by the surface temperature. Therefore, the variability of the surface temperature often results in inconsistent test results between different instruments.

This presentation provides an overview and data of surface temperatures when employing various outdoor (with concentrated solar radiation) and laboratory test technologies (xenon-arc instruments). Measurements are taken with different colored sensors to represent how the test conditions influence the full temperature range from light colored (white) to dark colored (black) materials. It is also demonstrated how temperature differences between different test scenarios can be compensated or mitigated by appropriate adjustment of the test parameters.

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Evaluation of the ASTM D7869-13 test method to predict the gloss and color retention of premium architectural finishes-II

Kurt Wood, Arkema, Inc.

Abstract

Recently we reported[1] on work seeking to understand the extent to which the new xenon arc-based accelerated weathering cycle, ASTM D7869-13, developed for automotive and aerospace coatings, might also be able to accurately predict the gloss and color retention of poly(vinylidene fluoride) (PVDF)-based premium architectural finishes. The ASTM D7869 cycle accurately reproduced Florida rank order gloss and color retention trends for PVDF-based coatings made with single (non-TiO_2) pigments, similar to several UV fluorescent cabinet cycles. However none of the accelerated cycles, including D7869, were found to accurately predict the rank order of rutile TiO_2 grades for Florida gloss retention, nor the magnitude and direction of color fade from organic pigment degradation in organic pigment/inorganic pigment blends. This paper follows up on that study to address the question of whether the ASTM D7869 cycle, or other accelerated weathering cycles, might nevertheless have some utility for industry standard or specification purposes, across resin lines, especially if the test is limited to specific reference colors or more ideally to specific reference pigments. This kind of approach is being examined by the SSPC C.1.8 fluoropolymer coatings committee, as a way to distinguish between fluorinated and conventional topcoat binders.

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[1] https://doi.org/10.1007/s11998-018-0050-y.

Assessment of polymer durability by accelerated photo-ageing experiments

Dr. Steeve Collin Centre National d'Evaluation de Photoprotection (CNEP)

Abstract:

The use of polymer or composite materials for outdoor applications raises the important issue of durability assessment. CNEP is a French applied research centre specialized in the study of polymer ageing and polymer durability. Since 1986, the main mission of CNEP is to provide to industrial customers an assessment of the durability of their final products containing polymers. This prediction involves a scientific approach based on the knowledge of the photodegradation mechanisms involved in the loss of functional properties. Understanding the reactions involved in polymer degradations also allows to design efficient stabilisation strategies to increase the polymer durability in actual use.

Under environmental stresses, i.e. light, heat and humidity, polymers are likely to lose their initial functional properties. These degradations are due to physicochemical modifications of the polymer structure. The end of life of the polymer is reached after periods of time that depend on the natural exposure conditions (climate, uses…) and the polymer formulation (kind of polymer, fillers, dye/pigment, UV and heat stabilizers…). The prediction of durability is therefore essential, in particular to prevent or anticipate premature degradations in actual use. The durability of polymer can be assessed by artificial ageing methods that must be 1) representative of natural ageing and 2) accelerated to limit the duration of the UV tests.

The objective of this paper is to present an accelerated method based on artificial exposures to medium pressure mercury vapour lamps. This method involves a physicochemical approach that consists in measuring the chemical modifications, and especially the oxidation level, occurring both in natural (actual) and artificial conditions. The comparison of the chemical evolution kinetics upon natural and artificial exposures allows the determination of an acceleration factor that is then used to predict the polymer durability, even for long-term uses. The reliability and the strength of this method is based on a scientific approach that focuses more on the chemical modifications responsible for the ageing rather than on the losses of the polymer functional properties.

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Novel laboratory accelerated weathering cycles for biodegradable plastics through an evaluation and comparison of accelerated weathering and natural exposure

Christopher Wallis , Polymateria Ltd

Abstract:

Plastic pollution has become a huge issue in recent years and whilst the focus remains very much upon marine based fugitive plastics, the data suggests that the problem on land is three times the scale[1]. Deploying solutions for the open natural environment is difficult due to the complexities of correlating laboratory outcomes with 'real world' outcomes. Previous efforts in this space have often used the same relatively harsh weathering cycles as those used by researchers looking to show the durability of a polymeric material. This has resulted in weathering cycles that will degrade a standard plastic equally as they would degrade a biodegradable plastic. We, on the other hand, have developed a novel weathering methodology that has been specifically designed to use the minimum amount of light, heat and moisture necessary to induce a chemical degradation within polymer matrix. The resulting by-products of weathering have been fully characterized by chemical analysis, as well as their bioavailability to biodegrade. These relatively less intense and shorter cycles provide the advantage of clearly distinguishing between an enhanced biodegradable plastic and a standard plastic. Chemical analysis of the polymers will be presented to show the effect of chemical transformations taking place, alongside a comparison of these accelerated cycles to natural exposure, hence demonstrating their effectiveness as a more realistic laboratory methodology for such polymeric materials.

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[1] Wallis, C. Terrestrial fugitive plastic packaging: the blind spot in resolving plastic pollution. *Green Materials*, DOI: 10.1680/jgma.19.00044.

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Weathering Acceleration Factors for Aromatic Polymers: Implications for Testing

James E. Pickett*[a], Olga Kuvshinnikova*[b], Li-Piin Sung[c],

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Abstract:

Laboratory accelerated weathering is useful only if the results have some relationship to performance under actual use conditions. Practitioners often desire side-by-side comparisons to select materials under the assumption that rankings are likely to be the same or that certain conditions have a reliable correlation factor to outdoors. However, it is becoming increasingly evident that different materials respond to accelerating conditions differently, so correlation factors vary among materials under the same exposure conditions or some conditions simply are non-predictive. Eight aromatic thermoplastics have been exposed in the NIST SPHERE to several levels of light intensity, temperature, humidity, and ultraviolet wavelengths to determine reciprocity, activation energies (E_a), moisture effects, and action spectra. Recent results show that a polyarylate copolymer and poly(acrylonitrile-*co*-butadiene-*co*-styrene) (ABS) give significantly different results than polycarbonate, polyesters, or poly(styrene-*co*-acrylonitrile) (SAN). The polyarylate has zero or slightly negative E_a while ABS has a higher E_a than the other polymers. ABS exhibits non-reciprocity while RPA exhibits unusual wavelength effects. Polyarylate, ABS, and SAN all exhibit increased degradation rates under very dry conditions while the other polymers do not. The results will be summarized and implications for accelerated weathering and service life prediction will be discussed, particularly the effect of UV sources that are greatly different from sunlight.

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Quantification of ‘Carbonyls’ via IR Spectroscopy – A Broader Perspective

Mathew Celina , Erik Linde Sandia National Laboratory

Abstract

All polymer degradation under oxidative conditions usually involves the participation/generation of some carbonyl containing species, i.e. ketones, aldehydes, amides, acids, and others, and their many derivatives. Carbonyl chemistry is an integral part of materials degradation pathways, mechanistic aspects and ultimately feeds into our predictive abilities as long as we consider ‘chemistry’. Carbonyls have excellent signatures in the IR and basic spectra for relative material comparisons are easily obtained. Yet quantification is much more challenging. Often we do not know the exact species that is involved; hence extinction coefficients have intrinsic uncertainty. ATR spectroscopy has additional uncertainty in terms of penetration depth and transmission IR is limited by films thickness. Considering the many details that affect spectral acquisition and quantification, we recognize that carbonyl quantification is surprisingly challenging. We therefore offer a pragmatic review of this topic. We wish to emphasize that there are broader variances than anticipated, in fact the combination of variances in exact species, extinction coefficient, contributions from neighboring convoluting peaks, matrix interaction phenomena and instrumental variations in primary IR spectral acquisition all point to large margins in carbonyl quantification. This has implications for some polymer aging studies and data analyses that rely on ‘carbonyl input’ for kinetic models or DLO interpretation.

Key words: Carbonyl Chemistry, IR Spectroscopy, Quantification, Variances, Experimental Parameters

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Wednesday Afternoon: Modelling.

This session seeks to combine the environmental stressors in both data collection and modeling. These experiments use unique weathering devices to craft a weathering environmental with multiple environmental stressors that are independently controlled. This ability to "dial-in" the desired environment allows for modeling with predictive capability. The predictions are further validated against actual outdoor exposure. The result is a model that can be applied to any weather condition and generate predictive material response with known uncertainty.

Discussion Leaders: Andy Francis, Karl-Anders Weiss, Matt McGreer

Time	Presenter	Title
2:00 PM- 2:30 PM	LiPiin Sung	Service life prediction for thermoplastics using multiple material properties from accelerated and outdoor weathering
2:30 PM- 3:00 PM	Yuming Lai	Characterizations of structure and property changes of high density polyethylene after accelerated UV
3:00 PM- 3:30 PM	Adam Pintar	Multivariate Statistical Models for Service Life Prediction of Polymers
3:30:PM- 4:00 PM		Break
4:00PM- 6:30 PM		Discussion

Service life prediction for thermoplastics using multiple material properties from accelerated and outdoor weathering

Li-Piin Sung, Kayla Callaway, Shih-Jia Shen, Chen-Yuan Lu, Awai Atchade, David Goodwin, Deborah Jacobs, Vanda Luu, William Hickling, Jacob Pickett, Thong Quoc Huynh, Adam Pintar, Christopher White, and Stephanie Watson

NIST

Abstract:

Recent results show that a statistical model using accelerated weathering property data (such as elongation at break values) collected on the NIST SPHERE (Simulated Photodegradation via High Energy Radiant Exposure) can be used for predicting the degradation of a model high-density polyethylene (PE) polymer system for outdoor exposure (in Florida, USA). This presentation reports ongoing research efforts for polyethylene terephthalate (PET) and other classes of thermoplastics using multiple materials properties. The objective of this study is to explore statistical analysis methods and modelling to establish weathering correlations on industrially relevant polymer chemistries/performance characteristics and outdoor exposure sites in conjunction with NIST exposure experiments. In addition to mechanical properties, chemical and optical properties were measured to evaluate and understand the degradation mechanism of the PET both under accelerated and outdoor natural weathering. Chemically different from PE, PET has a high glass transition temperature and low crystallinity, and so the effect of temperature and degradation mechanism may be different for these two polymer systems. Kinetics of degradation (Arrhenius relationship and activation energy) and reciprocity law will be investigated and used for modeling input.

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Characterizations of structure and property changes of high density polyethylene after accelerated UV weathering

Yuming Lai, Brian Landes, Ken Kearns, John O'Brien, Xiaoyun Chen, Shadid Askar, Todd Hogan

Dow Chemical

High density polyethylene (HDPE) resins exhibit high stiffness, cold temperature toughness and excellent chemical resistance and are therefore widely used for packaging and durable applications such as drums, intermediate bulk containers (IBC), recreation equipment, and other outdoor applications. Combinations of anti-oxidants and UV additives are typically blended with HDPE in order to protect resin's optical and mechanical properties against aging from environmental stressors including UV, heat and moisture. In this work, we studied stabilized and non-stabilized HDPE upon accelerated UV weathering and evaluated relationships between structure and functional group changes as well as mechanical and appearance properties

Multivariate Statistical Models for Service Life Prediction of Polymers

Adam L. Pintar[1] and Christopher C. White[2],

[1]National Institute of Standards and Technology Statistical Engineering Division,

[2]National Institute of Standards and Technology Materials and Structural Systems Division,

Abstract:

An important decision in service life prediction (SLP) is the selection of a degradation metric, i.e., how degradation will be measured. In many circumstances, there will be more than one metric or property of interest. Some properties help establish the mechanism of degradation, and some are functionally important. For example, FTIR spectroscopy provides information about the mechanism of degradation, but mechanical properties such as elongation at break determine useful life. Since it is expected *a priori* that measurements of degradation will be correlated, i.e. a high level of degradation for one metric will imply a high level of degradation for another, the data are inherently multivariate. Statistical analyses should recognize this structure. Consider the following analogy. It would not be surprising to find a male in the United States that is 1.75 m tall. However, it would be very surprising to find a 1 year old male that is 1.75 m tall. Age and height are strongly positively correlated (at least in the younger population). A description of the distribution of only ages, or only heights, would fail to recognize this structure. Analogously, high (or low) measurements of elongation-at-break and oxidation would tend to occur together. Predictions for both components that ignore this structure provide incomplete information. In this talk, a general strategy for predicting multivariate outdoor degradation using multivariate accelerated degradation data from laboratory experiments will be described. The basis of the procedure will be a statistical model for the laboratory data and the outdoor data, jointly. The general methodology will be demonstrated on a polymer of interest to the community.

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Dinner

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14TH & CURTIS STREETS *in the Denver Performing Arts Complex lower level of the Ellie Caulkins Opera House* DENVER, CO 80202

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About KT: In 1987, at the age of 25, self-taught chef and Denver native Kevin Taylor opened Zenith American Grill, serving his unique take on southwestern cuisine. Six months after opening, Zenith was among the three top-rated restaurants in Denver. Awards and recognition were garnered from local press and more than 25 national media outlets, including Bon Appetit, Restaurant Hospitality and GQ. Zenith also earned a prized four-star rating, securing Taylor's place on the culinary map.

Since then, Taylor has opened many successful restaurants, all appealing to those with a sophisticated palette, as well as a love for the arts. Although each restaurant's menu and style offers diners a singular experience, Taylor's belief in fresh ingredients and beautiful presentation is a common thread throughout all.

"When I cook, the first and foremost thought in my mind is that each guest needs to be wowed," says Taylor. "I take perfection seriously and am constantly looking for ways to improve myself as a chef, the food, the ambiance and setting, and how people feel when they dine in any of our restaurants. Food is just a portion of the overall guest experience; I often ask myself how contemporary cuisine can be better, and go from there."

https://www.ktrg.net/kevin-taylors-at-the-opera-house/

Thursday Morning: Photovoltaics

This session deals with accelerated testing and outdoor comparisons to support development of service life prediction models. The session also includes discussion of stress factors and methods, materials characterization, and application of degradation models

Discussion Leaders: Brad Ryland, Peter Hacke, Kurt Wood

Time	Presenter	Title
7:00 AM-8:00 AM		Breakfast. On your own.
8:00 AM-8:30 AM	David Miller	Degradation in Photovoltaic Encapsulation Strength of Attachment: Results of the First PVQAT TG5 Artificial Weathering Study
8:30 AM-9:00 AM	Xiahong Gu	Development of Methodology for Service Life Prediction of PV Backsheets
9:00 AM-9:30 AM	Laura T. Schelhas	Understanding PV Polymer Backsheet Degradation through X-ray Scattering
9:30 AM-10:00 AM	Coffee Break	
10:00 AM-10:30 AM	Peter Hacke	Combined-accelerated stress testing (C-AST) for service life prediction of PV modules
10:30 AM-11:00 AM	Karl-Anders Weiß	PV modelling
11:00 AM-11:30 AM	David Miller	Round-Robin Verification of Specimen Temperature During Accelerated Testing for the PVQAT TG5 Studies
11:30 AM-12:30 PM		Panel Discussion
12:30 PM-2:00 PM	LUNCH	

- Are we getting closer to performing accelerated tests in a way that will lead us to service life prediction?
- Are we testing materials, coupons, and modules under conditions that will reveal field-relevant failures?
- Are the materials analyses that we perform sufficiently sensitive and predictive indicators confirming degradation progressing toward failure?
- For which failure modes are we close to achieving service life prediction with satisfactory metrics, models and equations; which need a much more work?

Degradation in Photovoltaic Encapsulation Strength of Attachment: Results of the First PVQAT TG5 Artificial Weathering Study

David C. Miller,[1] Fahad Alharbi,[2] Afshin Andreas,[3] Jayesh G. Bokria,[4] David M. Burns,[5] Jaynae Bushong,[6] Xinxin Chen,[7] Dennis Dietz,[6] Sean Fowler,[8] Xiaohong Gu,[9] Aron Habte ,[3] Christian C. Honeker,[10] Michael D. Kempe,[1] Hussam Khonkar,[2] Michael Köhl,[11] Nancy H. Phillips,[12] Jorge Rivera,[6] Kurt P. Scott,[6] Ashish Singh,[13] and Allen F. Zielnik[6]

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ABSTRACT

Delamination of the encapsulant in photovoltaic (PV) module technology results in immediate optical loss and may enable subsequent corrosion or mechanical damage. The effects of artificial weathering were not previously known; therefore, an empirical study was performed to survey the factors most affecting adhesion, including: the UV source (i.e., Xe or fluorescent lamp(s)); the optical filters for the lamp; the chamber temperature; and the relative humidity. Natural weathering was also performed at locations, including: Golden, Miami, Phoenix, QiongHai, Riyadh, and Turpan. Specimens were constructed using a laminated glass/poly(ethylene-co-vinyl acetate). The compressive shear test (CST) was used to quantify the strength of attachment, taken as a proxy for adhesion. The fractography of select specimens (including cross-sectional microscopy) was used to verify the failure mode (delamination or decohesion). Additional analysis of the local solar spectrum as well as the specimen temperature was performed to interpret the results of natural weathering. The goals of this study include to identify the most significant stressors, clarify where strong coupling may occur between stressors, and validate accelerated test results relative to natural weathering. The importance of specimen conditioning (for moisture) and hygrometric degradation as well as the effects of UV degradation are identified in this study.

KEYWORDS

durability, EVA, reliability, xenon, UVA-340

Development of Methodology for Service Life Prediction of PV Backsheets

Xiaohong Gu*, Yadong Lyu, Debbie Stanley, Andrew Fairbrother, Li-Chieh Yu, Chen-An Wang, Yili Hong[1]

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Abstract:

Lack of reliable methodology for service life prediction is one of the most challenging problems that impedes the development of new photovoltaic (PV) technologies driven by module cost reduction. Some low-cost backsheet materials have passed IEC61215 and other relevant qualification tests for design and safety, but later have been identified with wide-spread failures in the field. Therefore, it's an urgent need to develop the reliable methodology for SLP of PV components. In this work, the effects of the environmental factors on backsheet degradation have been investigated using a commercial PPE backsheet (polyethylene terephthalate (PET/PET/ethylene-vinyl acetate (EVA)). The laboratory exposure of PPE films was performed on the NIST SPHERE *(Simulated Photodegradation via High Energy Radiant Exposure)* using a factorial design consisting of four UV intensities, four wavelengths, four temperatures and three relative humidities. The outdoor exposures were conducted in Florida, Arizona and Maryland. The chemical and optical degradation of the exposed backsheet films were quantified by attenuated total reflectance Fourier transform infrared (ATR-FTIR) and UV-visible spectroscopies. The reciprocity law and action spectrum were studied and the activation energy for PPE degradation was calculated. It was found that the degradation modes for samples exposed to SPHERE were similar to those exposed outdoors. A physical-based statistical model for predicting the service life of the PPE backsheet was established based on the SPHERE exposure data, and further validated by the field data from Florida, Arizona and Maryland. The results clearly show that the reliability-based methodology is capable of linking laboratory and field exposure data and predicting the service life of PV polymers.

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Understanding PV Polymer Backsheet Degradation through X-ray Scattering

Stephanie L. Moffitt[1], Michael Owen-Bellini[3], Pak Yan Yuen[2], David C. Miller[3], Donald Jenket[3], Ashley Maes[4], James Hartley[4], Todd Karin[5], Reinhold H. Dauskardt[2], Peter Hacke[3], Laura T. Schelhas[1]

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Abstract: As the cost of the photovoltaic (PV) modules drops there is an increasing need for more durable materials to increase module warranties up to 50 years. In order to reach these long lifetimes we must develop, de-risk, and enable the commercialization of improved materials and designs for PV modules, a key goal of the DuraMAT—or Durable Module Materials—Consortium. Our work, as part of DuraMAT, focuses on materials characterization and forensics to provide high-quality, in-depth characterization of photovoltaic (PV) module materials to our industrial and academic partners. These methods provide empirical data for understanding PV module failures and degradation mechanisms. Over the long-term, these data improve PV module materials development and design; ultimately leading to the discovery of new materials and adoption of materials from other industries. For this talk we will focus on our efforts to characterize PV module backsheet materials using X-ray scattering methods.

Backsheets are used to protect the PV cell from the environment and to create an insulating safety barrier, shielding the active electronic circuitry. It is most common for these backsheets to be layered composite structures consisting of polymers and inorganic pigments. While some of these backsheets have been successfully deployed in the field for many decades, others have begun to crack and break down after only a few years. To understand why these backsheets fail, we must understand how their properties are degrading after exposure to environmental stressors. Often, the key to understanding the origin of a material's properties, for example mechanical strength, can be understood by knowing the structure of that material. Small- and wide-angle X-ray scattering (SAXS and WAXS) have long been used in the wider polymer community to determine the nm- and Å- level structure of polymeric materials. However, these characterization techniques have not yet been widely adopted in the PV materials forensics community. However, X-ray scattering is a powerful technique for exploring backsheet polymer structure at the Å- (wide angle, WAXS) and nm- (small angle, SAXS) length-scale. Here we present the use of SAXS and WAXS to study pristine and aged polymer backsheets. The structural insight from these techniques can be used to corroborate the degradation induced by accelerated testing with the degradation seen in field-aged PV materials.

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Combined-accelerated stress testing (C-AST) for service life prediction of PV modules

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Abstract:

Standardized tests for PV modules are optimized for selected failure modes known in existing materials and designs. As a result, numerous new degradation modes are seen in field-deployed modules when new designs are introduced. We have developed combined-accelerated stress testing (C-AST) for PV modules, combining the stress factors of the natural environment in field representative combinations and levels, requiring fewer modules and fewer parallel tests, to discover known and unknown degradation modes. Because field results have shown that combinations of stresses have markedly greater impact than separate, factor-specific laboratory tests, application of stress levels in a combination appropriate to the natural environment can reduce test time, while also avoiding costly over overdesign.

Phase 1 of C-AST development was based on ASTM D7869; however, PV specific stress factors were added, including system voltage (the internal voltage in the series string of modules, up to 1500 V) that drives ionic current, applied mechanical stress simulating snow load, and freeze periods because PV modules must be capable of withstanding freezing. Additionally, peak sample temperature under illumination was adjusted upward to 90°C considering measured temperatures of some rooftop modules and localized joule heating occurring.

Multiple known field failures due to weaknesses in module designs could be detected in the samples tested through C-AST, such as backsheet yellowing, cracking, delamination, solder bond failures, and power loss from the cell by light-induced degradation. We however found at least two important shortcomings with the ASTM D7869 methodology. First, ASTM D7869 maintains approximately the maximum humidity levels of the natural environment. However, because some polymers shrink when the partial pressure of water in the atmosphere is low, and because humidity can act as plasticizer, we find it appropriate to also cyclically apply a dry test sequence to yield failures, as seen in some PVDF-based backsheets that fail in the field. Second, ASTM D7869 specifies no applied water spray and irradiance at the same time; however, we find that for PV modules, it is preferable to have the sample temperature and condensed water in the periods of lower light, 0.4 W/m^2/nm (340 nm), well controlled to systematically accelerate degradation mechanisms associated with ion transport.

Acceleration achieved in the C-AST cycle is being studied on a number of levels. The C-AST cycle based on the modified ASTM D7869 protocol as we apply it provides about 4.7 times the light energy of Miami. However, further acceleration of yellowing of the backsheet from increased temperature when exposing the front side of the module to light may be modeled using an Arrhenius formula. Also, thermomechanical fatigue is described using a Coffin-Manson-based expression. Electrochemical degradation of modules under system voltage potential is often associated with coulombs transferred. Examination of the relative rates of current flow between field and chamber-tested modules provides a direct acceleration factor.

With C-AST, we show that combining the stresses at levels within the statistical tails of what we see for fielded PV modules, with fewer modules and with fewer parallel tests, it is possible to

confidently discover potential weaknesses that are not known *a-priori* in new module designs, reduce residual risk, accelerate time to market and bankability, reduce costly overdesign, and apply known degradation rate equations to estimate service life with respect to the degradation mechanisms observed.

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Uncertainties in Degradation Rates Determination and Service Lifetime Prediction of PV Modules
(Solar and Renewable Electricity-PV lifetime forecast)

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Summary

As the share of photovoltaic (PV) keeps on increasing in the energy and power mix worldwide, makes it vital to know how the PV power decreases over time and how this may affect the financial figures. In order to accurately determine the degradation rates of PV modules, the evolution of power in real life operation has to be monitored. This not only requires waiting a considerable amount of time but also is expensive. In this case mathematical models are utilized to determine degradation rates in a shorter period of time but this comes with the question of how accurate the determined rates are. Different factors such as climatic data inputs, material parameters and not enough know how of degradation modes might lead to inaccurate/uncertainties in degradation rate determination. In this paper, two different factors are analyzed, one due to climatic data inputs and the other due to modelling assumption of a constant degradation rate. It is presented how these factors can lead to variations in PV modules lifetime predictions and how this affects the yield estimation.

Key-words: Degradation rates, climatic data, PV power, and yield estimation

1. Introduction

Prediction of the service lifetime of PV modules and systems is crucial for all PV stakeholders. For example, PV manufacturers benefit from setting realistic warranties and researchers can improve the quality of the PV materials in order to achieve a desired lifetime. In order to be able to develop reliable predictive models, a thorough understanding of the different sources of uncertainties in degradation rate determination is indispensable. For this reason, the paper highlights the sources of uncertainties from climatic data evaluation as input parameters and also uncertainties in service lifetime predictions by assuming a constant degradation rate throughout a modules lifetime.

2. Monitoring of Performance and Climatic data

Test-sites (Fig.1) in very different climates are used for the outdoor exposure testing of solar components with simultaneous monitoring of the climatic conditions and of sample properties (performance, surface temperatures, internal micro-climate e.g.) with a high time-resolution in order to find correlations between the external climate, sample stresses and long-term performance. At each test site, three identical monocrystalline silicon modules are under monitoring. The module in Gran Canaria has been exposed for over 7 years and the ones in Negev and Zugspitze have been exposed over 5 year outdoors. Apart from the performance measurements, the module temperature is also recorded every 10 minutes.

Fig. 1: The outdoor test facilities: Left to right: Alpine: Zugspitze, Germany; Desert: Negev, Israel; and Maritime: Gran Canaria, Spain.

3. Preliminary results

This section presents the first results of this study. On the one hand, different scenarios on climatic data such as UV irradiance, module temperature and temperature cycles estimations as models inputs and their impact on degradation rates determination have been accessed and will be presented in the final paper. In this abstract we show only the uncertainties in degradation rates determination caused by module temperatures estimation. On the other hand we show the effects of assuming a constant degradation rate in lifetime prediction. A time dependent degradation rate model has been proposed and by using indoor accelerated test damp heat datasets, a comparison with a constant degradation rate have been made. The comparison is later extended to outdoor conditions using climatic and performance data sets of the three climatic zones and the impact on yield estimation is evaluated. This will be presented in the final manuscript.

3.1. Uncertainties due to module temperature evaluation

The Peck's model (Lindig et al. 2018) proposed for degradation mechanisms influenced by humidity and temperatures such as corrosion is utilized in this study. The model takes the module temperature as an input instead of the ambient temperature. Many models have been proposed to evaluate the module temperature in outdoor conditions (Mora Segado, Carretero, and Sidrach-de-Cardona 2015). Two models: the model presented by David King (King, Boyson, and Kratochvil 2004), and the Faiman model (Faiman 2008), are applied to predict the annual mean temperatures in this study and uncertainties evaluated using real measured module temperatures of the mono-crystalline modules installed in the three climatic zones. Table I shows the calculated relative difference in percentage for the degradation rate determination using module temperatures evaluated using King's and Faiman models. The Faiman model shows a good performance compared to King's model. In general, temperature is a sensitive parameter hence small deviation in module temperature evaluation leads to high uncertainties. This can be explained by the Arrhenius temperature dependences in degradation rate models.

Tab. 1: Uncertainties due to module temperature T_m estimation

Location	Rate, T_m measured (%/year)	Rate, T_m King's (%/year)	Rate, T_m Faiman (%/year)	King's model Relative difference (%)	Faiman model Relative difference (%)
Negev	0.178	0.169	0.173	4.8	2.6
Canaria	0.115	0.154	0.137	25.2	15.9
Zugspitze	0.030	0.022	0.025	25.2	15.7

3.2. Uncertainties due to a constant degradation rate

Although most publications and authors who have worked on degradation analysis or proposed degradation models (Subramaniyan et al. 2018) usually assume constant degradation rates throughout the module lifetime. However, we assume that as the module ages, its components, especially the chemical properties are changing and deteriorating over time. The modules becomes more unstable and very susceptible to the loads, hence increasing the degradation rate. In this paper, a time dependent degradation rate is proposed (eq.1).

$$k_T(t) = k_{Tc} + \delta \times (1 + k_{Tc})^t \qquad \text{(eq. 1)}$$

Where $k_T(t)$ is a time dependent degradation rate, k_{Tc} is a constant initial degradation rate and δ is a scaling factor.

Differente damp heat test results were used to compare a constant and time dependent degradation rate. In all cases a model was first calibrated with on set of power degradation data for example at 2000 hours (see Fig.2 on the right). Then extrapolation using a constant rate and a time dependent rate was done, lastly by extending the measurements time (from 2000 to 4000 hours), made it possible to compare the two rates. From Fig.2 it can be clearly seen that there is a difference in extrapolations for the two rates. Extrapolation using a time dependent degradation rate is more constistent with the extended measurements. This is more visible for modules with higher degradation rates (Fig.2 on the right M03) and when extreme conditions are applied (Fig.2 left, at 95°C/85% in green). This result confirms the hypothesis that degradation rate increases as the module ages. Therefore, we show that extrapolation using a constant degradation rate leads to misleading interpretations and predictions. In the final manuscript this study will be extended to outdoor degradation rate determination as well as energy yield estimations to show how this could affect the yield predictions.

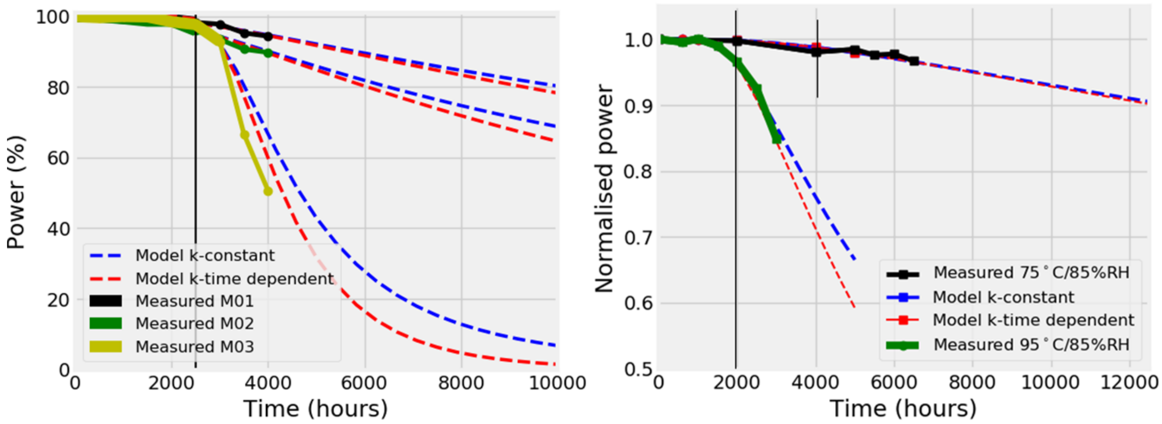

Fig. 2: Power degradation during DH test, in bold is the measured power and dotted blue is extrapolation using constant degradation rates and in red is the extrapolation using a time dependent rates. Black vertical lines show the calibration points.

4. Conclusion

The first part of this paper investigates the evaluation of uncertainties in degradation rate estimations due to the quality of climatic data. Different scenarios of climatic data as models inputs have been analysed and how they affect the estimation of degradation rate. The uncertainties in module temperature and temperature differences have a severe impact on degradation rate calculations. The second part of the paper investigates the consequences of using a constant degradation rate. As the first results we show the differences in extrapolations by a constant and a time dependent rate using damp heat power measurements. Using a time dependent degradation rate shows more consistent predictions in comparison with a constant rate. The next step is to extend the comparison to outdoor datasets in order to evaluate the impact on yield evaluation.

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Round-Robin Verification of Specimen Temperature During Accelerated Testing for the PVQAT TG5 Studies

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ABSTRACT

The specimen temperature has critical implications regarding the results and interpretation of accelerated testing. As the PV industry moves towards material- and component-testing, the verification of specimen temperature has increased importance. Motivating examples will be presented for comparison, including from the weathering equipment and other industries. The approach of temperature verification using a “round-robin” interlaboratory precision study will be described. Specific issues and examples will be presented from the recent PVQAT studies, including those experiments examining artificial- and natural- UV weathering. Artificial weathering experiments were verified against the recent IEC 62788-7-2 standard (xenon lamp, with ASTM D7869 filter). The issues of thermocouple size, masking of the thermocouples against radiative heat transfer from the chamber lamp, and verification of the chamber and black panel temperature are examined for artificial weathering. Natural weathering includes the locations of: Golden, CO; Miami, FL; Phoenix, AZ; Riyadh, SA, and Singapore, SG. The issues of coupon and fixture composition/geometry are highlighted for natural weathering.

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Thursday Afternoon: Standards and Implementation.

The number of independent studies on the degradation of specific materials and products, and their service life prediction, speaks to the need for better lifetime prediction methods, beyond standard testing. In this session, we will hear about examples of SLP implementation in the coatings and sealants industry, and about the critical role of industry standards in guiding the adoption and success of SLP practices. These talks will kick-off the post-break discussion where attendees are invited to map a successful roadmap for the implementation for SLP technology adoption though standards.

Discussion Leaders: Mat Celina, Michael Owen-Bellini, Laura Schelhas

Time	Presenter	Title
2:00 PM- 2:30 PM		Start at 2:30
2:30 PM- 3:00 PM	Anthony Griffin	Failure from the Start: Evolutionary Design of Polymeric Materials using Predicted Service Life Data as a Design Trait
3:00 PM- 3:30 PM	Florian Gast	Testing artificially aged silicone sealants for advanced applications
3:30:PM- 4:00 PM	David Burns	The Role of Industry Standards in Service Life Prediction
4:00PM- 4:30 PM		Break
4:30 PM- 6:30 PM		Discussion SLP standards and implementation.

Failure from the Start: Evolutionary Design of Polymeric Materials using Predicted Service Life Data as a Design Trait

Anthony Griffin , Erik Sapper

Kenneth N. Edwards Western Coatings Technology Center, Department of Chemistry & Biochemistry, California Polytechnic State University, San Luis Obispo, CA, 93407

Abstract: Shifting typical material design to incorporate service life prediction at the start of a project, rather than a final check, would increase efficiency of design space exploration by terminating doomed projects before synthesis has begun. Incorporation of machine learning and artificial intelligence to assess failure data of coating resins leads to the development of a predictive model that can assess service life of new materials. The use of a model such as this would create a closed-loop workflow that utilizes previous experimental results to improve learning and future design. Here we develop and validate a framework of service-life testing using accelerated laboratory weathering in commercial plastic materials and synthesized latex films. The photodegradation pathways of these materials are mapped to gloss reduction and modeled to fitness functions for evolutionary programming through genetic algorithms. A foundational database required for model development is built and initial predictions are examined through further synthesis and testing.

Testing artificially aged silicone sealants for advanced applications

Florian Gast Dr. Siebert Consulting Engineers

Abstract

Silicone sealants have been applied for more than 40 years to structurally bond glass onto steel or aluminum frames.

One of the reasons is the unique resistance to weathering in normal assembly situations. With vertically installed facades, there can be installation assemblies with horizontal silicone joints, on which standing water cannot be avoided. Despite the assumed, good weathering resistance of silicone, this situation must be investigated.

At the University of the German Federal armed forces Munich, Silicone samples were artificially aged in various chemical solutions and analyzed using microcomputer tomography and infrared spectroscopy to describe the ageing behavior.

The investigations show the suitability as well as challenges of the chosen methods for the description of the ageing behavior of silicone sealants.

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The Role of Industry Standards in Service Life Prediction

David M. Burns Multidisciplinary Gentleman Scientist

Abstract:

This presentation discusses the role industry standards play in promoting and supporting the expanding of service life prediction (SLP) within industry. It will review the state of SLP related standards activities and make recommendations for future initiatives. The underlying scientific and engineering concepts and methodology for effective and reliable SLP of products has been reported in the technical literature for more than 50 years. Yet to date, SLP is practiced by only a small handful of industrial laboratories to develop and commercialize products. After all this time why is it that SLP is not the common practice for evaluating the durability and estimating the service life of every product sold into durability critical applications? SLP differs substantially from the standard industry test protocols found in purchasing specifications for products. Industry standards focus on facilitating the initial sale by setting minimum performance levels after weathering and durability testing that serve to qualify products for entry into the marketplace. The weathering tests in these standards share a common format where products are judged on their ability to retain a defined minimum level of performance after a set number of exposure hours under a single set of conditions. In industry standards the emphasis is on the exposure conditions with the implicit assumption that all materials, all polymers, all products respond the same – a seriously flawed assumption. SLP focuses on quantifying actual durability by characterizing the response of the product to stress using careful and thorough application of science and engineering. In other words, SLP follows the same basic methodology used in all other engineering fields to assess product durability and reliability. In order for industry to adopt SLP more broadly there will need to be significant changes not just in their methodology for evaluating product durability, but also changes in how weathering and durability testing is viewed. Concerted efforts to (re)educate and guide product researchers and engineers in SLP methods and their benefits are needed to support the changes required. The industrial standards framework is well suited and positioned to be a major source of this education and guidance for scientists and engineers in commercial laboratories and manufacturing. This talk will present current initiatives and make recommendations for future new SLP standards.

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Poster Session

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Discussion Leaders:

Presenter	Title
Christopher Wallis and Celine Moreira	Designed environmental interactions of biodegradable plastics with air, light and moisture: Correlating novel laboratory weathering methodologies with natural exposure.
David Burns and Jim Pickett	Applying SLP to Industrial R&D: Material-appropriate accelerated weathering
Michael Owen-Bellini	Validating Advanced Stress Testing Protocols Using Analysis of Degraded Polyvinylidene Fluoride-Based Backsheet Films
Olga Kuvshinnikova* and James E. Pickett	Is ASTM D7869 Accelerated Weathering More Predictive Than ISO4892-2 for Uncoated Plastics?
James E. Pickett	How the Relative Photodegradation Rates of Polymers Depend on the UV Source

Designed environmental interactions of biodegradable plastics with air, light and moisture: Correlating novel laboratory weathering methodologies with natural exposure

Christopher Wallis and Celine Moreira Polymateria Ltd Imperial College, London,

Abstract Title:**.**

We live in an era known as the "Plastic Age". Over the last decades the production and consumption of plastics have increased drastically. Furthermore, since the industrial revolution in the 20th century people tend to have the idea of constantly purchasing goods which is brought by advertisement, globalization and media creating a culture of use-and-dispose. Due to its versatility and cheap cost plastics have become ubiquitous and indispensable packaging products in societies daily life. However, due to their inert physical and chemical properties, they have become a major concern for the environment due to inadequate global waste management methods. Plastic waste affects various ecosystems, including the much-publicized marine environments, with over 250,000 tons of plastics currently floating in the ocean, to which most marine species confuse as some sort of food. It is the much less reported land environments, however, where even higher quantities of plastic pollution are accumulating, nearly three time more than in the oceans.[1] The main types of plastic waste are food-related packaging which contributes to one third of plastic production worldwide.[2] Biodegradable plastics are one of a range of efforts being employed to tackle global plastic pollution, but difficulties are encountered when correlating laboratory outcomes with natural exposure to help define the "real world" performance of the biodegradable plastic. According to ASTM D4329 – *Standard practice for Fluorescent UV exposure of Plastics,* the durability and persistence of plastics can be tested through exposure to light, heat and water to induce property changes associated with end-use conditions. In most cases, the weathering cycles used are designed for demonstrating the durability of plastics and as a result testing often causes deterioration even in a standard plastic product, which will not correlate to real-life scenarios. Polymateria has developed a weathering cycle which has been specifically designed to use the minimal amount of each environmental stimuli - light, air and moisture - necessary to induce chemical degradation within the plastic material that contains Polymateria's Biotransformation technology. Furthermore, outdoor exposure was performed in order to correlate our accelerated laboratory methodologies with natural exposure. We will present the chemical analysis and weathering data (accelerated vs natural) to demonstrate the interaction of the environment, namely, air, light and moisture with the plastic, including its effect on the chemical transformation taking place therein. Correlations between results obtained from accelerated laboratory and natural exposure studies will also be presented, demonstrating its effectiveness as a more realistic laboratory methodology for evaluating biodegradable plastics.

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[1] Wallis, C. Terrestrial fugitive plastic packaging: the blind spot in resolving plastic pollution. Green Materials, DOI: 10.1680/jgma.19.00044.

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Applying SLP to Industrial R&D: Material-appropriate accelerated weathering

David Burns and Jim PickettIndependent Scientist and James Pickett Consulting, LLC, respectively

Abstract :

The core of SLP is quantifying the sensitivity of a specific product construction to solar radiation, heat and moisture, the three primary environmental stresses. Conducting a full SLP analysis requires employing multiple exposure methods that systematically vary these stresses to fully characterize the product's sensitivity. This type of full characterization should ideally be run on each design iteration during development of a product. However, to do so requires considerable resources and time, especially access to multiple weathering apparatus and trained operators. This lack of resources has been cited as a significant barrier to the board implementation of SLP methodology within industry R&D laboratories. Product development in an industrial laboratory most commonly involves an initial prototype construction followed by iterations to optimize the design. One can take advantage of the similarities in materials within these iterations to create SLP-derived custom artificial weathering method tailored to the sensitivity of the materials in the core construction. Such material-appropriate weathering methods maximize "acceleration" of the degradation rate along the same pathways as the in-service exposures to maintain good correlation to the real-world exposure. While no single weathering method can predict the durability of a material under all exposure conditions, these customized methods can then be used for rapid high throughput and reliable screening of iterations during the development and optimization phases of product development. This poster will provide a process overview for developing material-appropriate weathering methods for industrial R&D.

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Validating Advanced Stress Testing Protocols Using Analysis of Degraded Polyvinylidene Fluoride-Based Backsheet Films

Michael Owen-Bellini, Stephanie L. Moffitt, Archana Sinha, David C. Miller, Ashley M. Maes, James Y. Hartley, Todd Karin, Donald R. Jenket, Jared Tracy, Peter Hacke, Laura T. Schelhas

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Abstract:

Abstract description (500 words or less): Polyvinylidene fluoride (PVDF)-based backsheet films are amongst the more common materials used in modern photovoltaic (PV) modules. PVDF is a direct competitor to other fluoropolymer-based films such as polyvinyl fluoride (PVF). However, in recent years some PVDF-based products have shown early failures, including cracking. One such product, here referred to as “PPF” has been known to fail within 7 years of field-deployment. With PV module product warranties presently being at least 25 years, this represents a significant module reliability issue. However, PPF passed qualification testing, suggesting insufficient design qualification practices. Recently, more advanced protocols have been developed which utilize sequential- and combined-stress testing to better replicate the conditions experienced by PV modules in the natural environment and ultimately detect weaknesses in materials and bills of materials. These new accelerated tests have previously been demonstrated to be effective at reproducing field-failure of PPF. In this work, we reveal the chemical, structural and mechanical changes that lead to failure through the application of various analysis techniques including: Fourier-transform infrared spectroscopy (FTIR), small- and wide-angle X-ray scattering (SAXS/WAXS), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), micro-indentation, and mechanical tensile (elongation-to-break) tests. A reduction in fracture toughness (enabling cracking) is inferred from simultaneous changes in other mechanical characteristics (creep, modulus, hardness) and the crystalline structure. We find that the outer, PVDF-containing layer, undergoes a reduction in fracture toughness which could be due to an increase in crystallinity and change in the crystalline phase of the material. The outer layer of PPF is blended with poly(methyl methacrylate) (“PMMA”), which we find to deplete through aging, potentially contributing to the observed change in crystallinity. We demonstrate that the mechanisms induced by combined-stress testing are the same as those which develop in the field. Furthermore, we compare the degradation modes invoked in industry safety- and qualification-testing to understand why failure was not detected there and to highlight the shortcomings of the existing tests.

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Is ASTM D7869 Accelerated Weathering More Predictive Than ISO4892-2 for Uncoated Plastics?

Olga Kuvshinnikovaand James E. Pickett
SABIC Innovative Plastics

Abstract:

The ASTM D7869 xenon arc weathering standard, issued in 2013, was designed for transportation coatings, but is being increasingly applied as a qualification test for uncoated plastics despite a lack of data showing whether or not it is better than other standards. A series of 31 aromatic engineering thermoplastic formulations, including white, black and transparent samples, was exposed near Miami, Florida for 36 months and also subjected to artificial weathering according to ASTM D7869 and twice to modified ISO 4892-2 conditions. The modifications were using the same lamp filters specified by D7869 (Atlas Right Light®) and using an irradiance of 0.75 $W/m^2/nm$ at 340 nm. Accelerated data were compared to Florida data using correlation factors calculated on the basis of UV radiant energy and temperature. Exposures of 2.5 MJ/m^2 at 340 nm in ASTM D7869 and 3.0 MJ/m^2 at 340 nm for modified ISO 4892-2 were expected to be equivalent to 12 months in Florida. One set of ISO exposures used 4.0 MJ/m^2 correlation factor because that run was unexpectedly mild for reasons not fully understood. The results show generally good prediction of yellowing and % transmission, but only fair to poor predictions for gloss loss and % haze. There was little or no difference between the quality of predictions for the two exposure conditions. The primary advantage to ASTM D7869 is that it requires the use of a light source that very closely matches the spectral power distribution of sunlight, which gives good predictability for many properties, while that source is only one of several options for ISO 4892-2.

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How the Relative Photodegradation Rates of Polymers Depend on the UV Source

James E. Pickett , Consultant, Schenectady, NY

Abstract:

Many artificial UV sources are used to do accelerated weathering studies on polymers and coatings. Nearly any source can be used for research on a single material, but many times standards and qualification tests are used to test and compare different materials side-by-side under the same conditions. This is often considered to be fair, but different materials respond to UV wavelengths differently. The question becomes, "Can you get valid results comparing different materials side-by-side with UV sources that are unlike sunlight?" Since no artificial UV source is perfect, how good to you have to be? Many polymers respond to UV wavelengths approximately exponentially. This exponential sensitivity can be convoluted with the spectral power distributions of UV sources and compared to the response from sunlight. Mathematical comparisons of four polymers with different exponential action spectra show that state-of-the-art xenon arc filters and fluorescent UVA 340 lamps give responses within a range of 10% for all four materials while metal halide, carbon arc, and extended UV xenon arc do not, with relative responses varying by 70% or more among materials. Side-by-side comparisons and qualification testing using the latter sources are not valid unless corrected for wavelength sensitivity of the materials.

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Friday Morning: Mechanical strain.

This session focuses on assessing the durability and service life of polymeric materials which are either relatively new materials or are being used in new applications or configurations. Presentations include the effect of temperature, moisture and ultraviolet (UV) light on polymeric interlayers used in safety glass. Also discussed is temperature and humidity exposure, as well as alkaline exposure to simulate attachment to concrete, of silicones used as membranes in construction and as sealants for glass panels. Other topics include UV, temperature, and moisture exposure of composites used as coatings and strengthening retrofits in civil infrastructure as well as degradation of different elastomers exposed to gamma radiation under different temperatures. In general, the talks focus on methods to assess material degradation in these applications, with many of the methods involving mechanical strain. In some cases, rate constants and modeling of degradation modes are discussed.

Discussion Leaders: David Goodwin, Chris White, Barbara Siebert

Time	Presenter	Title
7:00 AM- 8:00 AM		Breakfast. On your own.
8:00 AM- 8:30 AM	Barbara Siebert	Influences on the service life of silicones in the edge seal of insulating glass units
8:30 AM- 9:00 AM	Masayuki Ito	Temperature dependence of radiation induced degradation of chlorosulfonyl polyethylene and chloroprene elastomer
9:00 AM- 9:30 AM	Geralt Siebert	Creeping behaviour of PVB under different temperatures and humidity
9:30 AM- 10:00 AM		
10:00 AM- 10:30 AM	Marzieh Riahinezhad.	Investigation onto the durability and service life prediction of silicone membrane in construction applications
10:30 AM- 11:00 AM	David Goodwin	Methods to assess polymer composite degradation in civil infrastructure applications
11:00 AM- 11:30 AM	Alexander Pauli	Investigation of the mechanical behaviour of PVB interlayers due to UV ageing in the context of large-scale testing
11:30 AM- 12:00 PM		Panel Discussion
12:00 AM- 1:00 PM		
1:00 PM- 2:30 PM		Wrap up Items.

Influences on the service life of silicones in the edge seal of insulating glass units

Barbara Siebert   Dr. Siebert Consulting Engineers

Abstract:

Insulating glass units (IGU) are standard applications. The edge sealing – often made of silicone gluing - is to be used to provide a hermetic structural edge seal to an insulating glass unit. However, the IGU's are being used more and more often under complicated boundary conditions: These include all-glass corners in high-rise buildings, glazing with large climatic loads in the space between the panes or large-format glazing. From the expert's point of view, there are more and more cases of damage here. This paper is intended to address the aspects relating to the durability of the edge seal from practical experience of the author. The service life prediction of these mostly silicone adhesives is of course a very important aspect for such applications. The following points will be dealt with:

- Service life prediction of "standard" IGU's about the durability of the edge compound

- Structural design in accordance with the "Guideline for European Technical Approval for Structural Sealant Glazing Systems (ETAG 002) or alternatively with a special permit.

- Additional loads to be expected from a static point of view for the scenarios or applications mentioned above

- Frequent problems with incompatibility of materials or unsuitable substrates

- Practical examples (high-rise building with all-glass corners, high-rise building with tightly curved IGU's, all-glass corner with compatibility problems)

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Temperature dependence of radiation induced degradation of chlorosulfonyl polyethylene and chloroprene elastomer.

Masayuki Ito Waseda University

Abstract

1. Changes in mechanical property

Two kinds of chlorosulfonyl polyethylene elastomer and two kinds of chloroprene elastomer, both of which have different compounding formula, were investigated. The samples were irradiated with Co-60 γ ray at constant temperature and constant dose rate of 5.0 kGy/h. The temperature was ranged from 70^{o}C to 150^{o}C. The maximum dose was 1.8 MGy.

To compare the thermal resistance and the radiation durability of the elastomers, heat aging was performed at 125^{o}C and 140^{o}C. Tensile properties of the samples were measured at room temperature after aging. The modulus of the both elastomer increased by irradiation. This tendency increased with a rise in temperature. Ultimate elongation decreased with increasing modulus.

The ratio of scission and crosslinking occurred during irradiation was analyzed by using “modulus-ultimate elongation profile”. The results suggested that crosslinking predominated in all conditions of this experiment. It was found that chlorosulfonyl polyethylene elastomer has better radiation resistant properties than chloroprene elastomer. The balance of the durability for heat and radiation of two elastomers depended on the compounding formula of the elastomer in the experiment.

2. Synergistic relationship between heat and radiation

The rate constant of chemical stress relaxation reflects the rate of molecular chain scission by heat and/or radiation. The “coefficient of synergism (E’)” was proposed to express the degree of synergistic relationship quantitatively between heat and radiation by equation (1) [1].

$$K(h+r) = K(h) + \text{constant} \times I^{\alpha} \exp(E'/RT) \quad (1)$$

K(h+r) is rate constant of heat and radiation and K(h) is that of heat alone at a given temperature. I is dose rate, α is dose rate exponent which was mostly about 1.0.

E’ depended on the compounding formula of the given elastomer. The value of chlorosulfonyl polyethylene elastomer use in this experiment was 29.0 kJ/mol and 52.1 kJ/mol.

Reference

[1] M. Ito, *Radiant Phys. Chem*., **18**, 653-660 (1981)

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Creeping behavior of PVB under different temperatures and humidity

Geralt Siebert, Martin Botz, Klaus Wilhelm Bundeswehr University Munich, Germany

Abstract:

PVB is widely used as material for interlayers of laminated safety glass. In the intact status, the interlayer is protected from moisture by the glass plies, only the edges are possibly effected in case of high humidity levels. In case of a broken laminated glass element, the situation is different. Regarding the influence of temperature and characterizing the material, a lot of research work was carried out in the past: only PVB material or laminated together with glass, on small scale as well as on large scale samples. For showing effect of temperature on full size samples we have carried out tests in climatic chamber under different temperatures.

It is well known, that PVB is not only temperature but also moisture-sensitive material, so one of course might expect an influence. Regarding effect of moisture creep tests of different interlayer-materials at different moisture and loading levels were carried out. As a first step, from the testing results a procedure comparable to time-temperature-superposition method was applied – and it looks very promising. Full size testing under different moisture conditions is the next step to be carried out.

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Investigation onto the Durability and Service Life Prediction of Silicone Membranes in Construction Applications

Marzieh Riahinezhad[1*], Jiyuan Wu[1], Itzel Lopez-Carreon[1], Peter Collins[1], Olga Naboka[1], Jocelyn Johansen[2] and J-F. Masson[1]

[1] Construction Research Centre, National Research Council of Canada
[2] CSL Silicones Inc.

Abstract:

Silicone elastomers have been used as construction sealants for decades. In this application, the elastomer is generally based on polydimethylsiloxane (PDMS). More recently, silicone elastomers have been used in construction applications to protect the roofs and walls of buildings, where they are installed as thin membranes to protect against water entry and minimize the leakage of air infiltrating or exfiltrating the assembly. As applications for the use of silicone membranes grow, these membranes may in time be used to waterproof concrete structures including, for instance, the surfaces of parking garages, dams, tunnels, and other buried structures. On concrete structures, the silicone products would be in contact with an alkaline surface at a pH in a range of 12 to 13. It is reported in the literature that PDMS is sensitive to alkaline hydrolysis; with a significantly lower activation energy for hydrolysis when PDMS is in contact with a base. It is nowadays common for construction applications to seek a service-life well in excess of 25 years, sometimes 50 years. It is therefore of interest to investigate the alkali resistance of silicone membranes to estimate their long-term in-service performance.

In this work, the alkaline resistance of silicone products is investigated. Different silicone membranes with varied formulation was studied. These membranes contained various types of fillers and pigments, and they had different cure chemistries, including, one-component and two- component room temperature vulcanization, and also high-temperature vulcanization. The alkali resistance of the silicone products was investigated by optical and scanning electron microscopy to highlight changes in surface morphology that may affect membrane adhesion to concrete. In addition, the mechanical properties of the silicone membranes were assessed by dynamic mechanical analysis (DMA) to monitor changes in viscoelastic properties in typical service conditions, and micro-indentation was performed to look into the changes in the modulus of the materials at room temperature and to compare with DMA data. From the results, the service-life of silicone membranes was estimated. The results demonstrated that silicone membranes are generally resistant to alkali degradation typical of concrete, however, the presence of some pigments and/or fillers can limit low temperature performance. It is also shown that the use of a standard method of aging silicone sealants in an alkaline solution is not appropriate for durability assessment and service-life prediction.

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Methods to assess polymer composite degradation in civil infrastructure applications

David G. Goodwin Jr., Mariam Hasan, Shih Jia , Katrina Carlin, Trinny Lai, Chen Yuan Lu, Rick Eason, Tinh Nguyen, Jazalyn Dukes, Siamak Sattar, and Lipiin Sung

NIST.

Abstract:

Polymer composites, or polymers that contain additional materials to achieve synergistic or improved properties, are increasingly being used in the civil engineering sector to increase the strength of structural components, decrease corrosion, and shorten installation times. Fiber reinforced composites made from glass and carbon fibers are most commonly used to strengthen and seismically retrofit structural components. Polymer nanocomposites, or polymers containing nanomaterial fillers such as carbon nanotubes and graphene, are predominantly in the research and development stages but have the potential for use as anti-corrosion coatings, crack fillers, compatibilizers for fibers, dampening materials, and low friction materials at joints. In many civil engineering applications, both FRP composites and polymer nanocomposites are exposed to outdoor environments for extended periods of time and can weather differently from neat polymer systems. New measurement science approaches or application of measurement science approaches useful in other fields are often necessary since polymer composite transformations may not be captured by traditional chemical and mechanical measurements. Furthermore, measurement science approaches should be tailored to assess performance losses of polymer composites in their specific applications for realistic service life prediction. In this presentation, several measurement science approaches will be discussed for degraded polymer composites based on their application. In the case of degraded polymer nanocomposites used for anti-corrosion coatings, the barrier properties can be affected by nanomaterial transformation, surface accumulation of carbonaceous nanomaterials, and coating thickness loss. Thus, these properties were evaluated using Raman spectroscopy, surface modulus measurements with AFM, laser scanning confocal microscopy, and scanning electron microscopy. For degraded FRP composites, debonding from concrete during three-point bending tests and pull-off tests, correlation of polymer matrix oxidation to FRP composite tensile property loss, and infrared thermography to measure the size of debonding areas were able to generate useful data for service life prediction. In many cases, measurement science approaches for one composite type can be applied to other composite types as will be demonstrated with a few measurements useful for both FRP composites and polymer nanocomposites. Ultimately, an increased variety of measurement science approaches would be beneficial to service life prediction with the increasing number of polymer composite materials on the market.

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Investigation of the mechanical behavior of PVB interlayers due to UV ageing in the context of large scale testing

Alexander Pauli, Geralt Siebert   Bundeswehr University Munich

Abstract:

As laminated safety glass is becoming increasingly important, especially the polymeric interlayer has come into focus. In order to be able to make predictions regarding the life time of laminated safety glass, among other things it is very important to investigate the effect of UV radiation.

Therefore, in order to get information about the influence of UV radiation on laminated safety glass and the polymeric interlayer, from a mechanical perspective, a comparison between aged and unaged test samples was carried out. Therefore the specimen were aged under UV radiation according to DIN EN ISO 12543-4 and then tested at different temperatures and load durations, by conducting four point bending creep tests. For a respective comparison between the mechanical behavior of unaged and aged specimen, unaged panels were tested the same way. In the end the shear moduli were evaluated for each sample by the use of a meta modelling in the context of a finite element analysis.

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