2009 BFRL Project Description

Project Title: Service Life Prediction for Building Joint Sealants

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Co-Investigator(s):

BFRL Program: Service Life Prediction of Nanostructured Polymeric Materials

Objective: Develop, implement, and transfer to our industrial consortium partners a reliability-based service life prediction methodology for sealants that has been validated for linking field and laboratory exposure results.

Problem:

What is the problem? No measurement science exists to predict the service life of sealant materials. Field degradation of sealants is caused by four primary weathering factors--temperature, humidity, spectral ultra-violet radiation, and static and cyclic mechanical load. Critical to the performance for sealants is their ability to span and seal gaps between dissimilar building materials. Common diurnal strain deformations are typically ± 7% while common annual strain deformation are ~ ± 25%. When exposed outdoors, molecular changes occur in a sealant that changes a sealant's strain behavior. Eventually, these changes reach a critical level, whereupon the sealant fails. Characterizing these molecular changes and attributing them to specific exposure conditions will enable the derivation and validation of predictive models for sealants exposed anywhere outdoors.

Why is it hard to solve? Sealant materials inherently exhibit non-linear viscoelastic response to any imposed load (mechanical, thermal, or chemical). As such, whenever a sealant undergoes a mechanical strain, this strain is viscoelastically relaxing in time scales ranging from minutes to months. Assessing the molecular changes in the sealant requires straining the sample and measuring the stress response. As the sealant is constantly changing and responding to applied strain, modeling these temporal variations in modulus to the environmental factors is a technical and scientific challenge. The measured modulus is dependent on specific strain level, time required to impose the strain, and strain history.

How is it solved today, and by whom? Currently used methods to assess durability are empirical and were never designed to predict performance; instead, they were designed to make simple performance comparisons. These methods generally fall into two categories: (1) threshold based methods (ASTM C719) which impose a series of serial challenges after which the sealant is visually evaluated and (2) multiyear outdoor exposure tests involving no strain , again evaluated with visual inspection. Visual evaluation does not provide any understanding of the non-linear viscoelastic modulus or the molecular changes occurring during exposure that

precede failure. Applied strain and the corresponding stress, which are critical components to the sealant performance, are not monitored in these methods.

Why BFRL? BFRL possesses three unique attributes: 1) unique exposure facilities (SPHERE), 2) personnel familiar with rheological characterization, and 3) strong mutually beneficial relationships with the sealant industry. This research will deliver critical predictive models for service life to the sealant industry (a significant part of the US building industry) and continue the global leadership in service life prediction performance-based standards.

Approach:

What is the new technical idea? Combining a reliability-based approach with a cumulative damage model has been successful in generating databases of dose-damage response leading to models with predictive capability for the agricultural, photographic, imaging, and radiation exposure industries. These models have been used to confirm common mechanisms of activity in both the laboratory and outdoor exposures and develop predictive models based on statistical or analytical approaches. The new technical idea is to replicate these successes and bring these approaches to the prediction of sealant in-service performance. This will involve developing precise instrumentation, characterization and exposure protocols, multivariable databases, and quantitative mathematical models. Four principle factors are considered critical to the aging of sealant: temperature, humidity, ultra-violet radiation, and imposed mechanical strain. It is critical in the laboratory to control and monitor each of these factors. By using a stress-relaxation experiment to characterize the non-linear viscoelastic modulus of the sealant before and after exposure, the rate of molecular changes within the sealant can be attributed the specific exposure conditions.

Why can we succeed now? The NIST SPHERE delivers uniform, precise, accurate, and temporally stable temperature, humidity, and ultra-violet radiation. Modification of the environmental chambers to apply strain to multiple samples has recently been accomplished. Additionally, outdoor exposure instruments have been developed to impose dynamic strain during the exposure.

What is the research plan? There are four measurement science needs previously identified: (1) *development of characterization protocol,(2) monitored outdoor exposure that included applied strain, (3) controlled indoor exposure including applied strain,(4) development of databases and resulting models with predictive capability*.

The first measurement need will motivate the development of a characterization method that allows precise, repeatable determinations of a sealant's modulus, via a stress relaxation measurement at predetermined strains. Precise, repeatable characterization of the modulus enables attribution of the exposure conditions to the rate of molecular change within the sealant. Understanding how the long term exposure to strain affects the sealant properties and dimensions is an ongoing measurement challenge to be addressed.

The second major measurement science need is to develop engineered outdoor exposure protocols where mechanical strain to a sealant can be applied and precisely and accurately monitored. For commercial structures, the sealant should be strained proportionally to changes in temperature. Design, construction and use of engineered outdoor sealant exposure devices

have produced quantitative information that can be linked to the results generated in laboratory studies. Based on this knowledge, it has become clear that, in addition to other weathering factors, the strain imposed on a sealant is a critical parameter for linking field and laboratory results. Modifications to our existing equipment to better make such measurements will be a major focus of our efforts.

The third measurement need is the development of indoor exposure protocols used on the SPHERE that can actively characterize the modulus of sealant materials proceeding and following controlled exposure to a preselected combination of the four major weathering elements. Significant progress has been made on this measurement challenge. We intend to design, construct, and modify the existing exposure chamber to expose sealant samples to 5 ^{o}C (the lowest temperature we can currently exposure our materials in the laboratory is 30 ^{o}C).

The fourth measurement need is the creation of databases of exposure from both indoor and outdoor data sources, which will be used in developing predictive models. The model development will be in collaboration with Prof. Bill Meeker of Iowa State University (ISU), who was successful in developing a similar model for clear epoxy coatings. Preliminary model development will proceed.

Recent Results: In 2008, the following outputs, outcomes and impacts were delivered:

<u>Outputs</u>

- Renewed CRADA agreements with nine sealant companies for Phase III
- Hosted two industry workshops to review progress of consortial research.
- Published six peer reviewed papers, four book chapters, six proceedings papers:

  C. C. White, D. L. Hunston, S. Williams, "Studies on the Effect of Movement During the Cure on the Mechanical Properties of Building Joint Sealant" Polymer Engineering and Science (in WERB)

  C. C. White, D. L. Hunston, K. T. Tan, "Effect of Strain on the Modulus of Sealants Exposed to the Outdoors" Journal of ASTM International (accepted and in press)

  C.W. White, K.T. Tan, D.Hunston, “Durability of Building Joint Sealants” Proceedings of the 4th International Symposium on Service Life Prediction - Global Perspectives. J.W. Martin, R.A. Ryntz and R.A. Dickie (Eds.), 2008

  C. C. White, "Studies on the Effect of Movement During the Cure on the Mechanical Properties of Building Joint Sealant" Polymer Degradation and Stability (in WERB)

  K.T. Tan, B. Vogt, C.C. White, J. Goldman and D.L. Hunston, “Understanding mechanisms of adhesion loss at and above critical relative humidity”, Proceedings of the 30th Annual Meeting of the Adhesion Society, Inc., Feb. 19-22, 2007, Tampa, FL, pp.160-162 .

C.C. White, D.L. Hunston and K.T. Tan, “Effect of strain on durability of model elastomers”, Proceedings of the 233th ACS Annual Meeting, Mar. 25-29, 2007, Chicago, IL.

C.C. White, D.L. Hunston and K.T. Tan, “Strain affects the solubility of elastomers”, Proceedings of the 79th Annual Meeting of the Society of Rheology, Oct. 7-22, 2007, Salt Lake City, UT.

D. L. Hunston, K. T. Tan, C. C. White, "The Surprising Affects of Strain on the Long Term Rheology of Filled Viscoelastic Solids (Building Joint Sealant)" Proceedings of the XVth International Congress on Rheology, August 2008.

K. T. Tan, C. C. White, C. Clerici, D. L. Hunston, B. Vogt, S. Satija, J. Goldman, K. Steffens, "Mechanisms of Moisture Attack in Adhesive bonds Exposed to High Humidity" 10th International Conference on the Science and Technlogy of Adhesion and Adhesives, Oxford, United Kingdom, September 2008.

Outcomes

- Significant reduction in the relative standard uncertainty of the SPHERE-based weathering device from 20 % to less than 5 %. (industry-state-of-art is 5% rsu)
- Demonstrated that applying strain to a sealant affects its water solubility. This observation has provided insight into observed chemical and mechanical responses of our exposed sealants.

Impacts

- One consortium member has adopted the practice of simultaneous exposure to multiple weathering factors in new product development pioneered by this project. Two companies have asked for a commercially available version of the SPHERE for sealant testing.

Standards and Codes: Active member of ASTM C24, building seals and sealants, work item started in C24 on standard for characterizing building joint sealant.