**EL Program:** **Sustainable Engineered Materials**

**Program Manager:** Aaron Forster, Division 731

**Associate Program Manager:** None

**Strategic Goal:** Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure

**Date Prepared:** May 31, 2013

**Summary:** The standards used to classify and specify materials used in infrastructure, construction, and manufacturing are not able to ensure sustainable performance for the materials, because they are not adequately based on a measurement science foundation that addresses essential materials issues. This materials program approaches the solution of this problem from the perspective of service life prediction, a crucial sustainability metric, and applies this concept to polymer composites and concrete. These two material thrusts will develop measurement science composed of a combination of characterization, performance measurement, accelerated durability tests, and modeling to develop standards that will be used by industry and specified by end-users in these broad application areas to enable service life prediction and thus help to ensure sustainable materials performance.

**Objective:** To develop and deploy advances in measurement science for sustainable materials used in manufacturing and construction, including cementitious and polymer composite materials, by 2016.

**What is the problem?** *The standards used to classify and specify materials used in infrastructure and manufacturing are not able to ensure sustainable performance for the materials, because they are not adequately based on a measurement science foundation that addresses essential materials issues and enables service life prediction (SLP)*. The main material classes that are common to the industry sectors mentioned above are steel, concrete, and polymer composites. This program will focus on concrete and polymer composites. However, essentially all exposed steel is protected by a corrosion barrier, which is usually a filled polymer coating or concrete, so that this program's results will also directly affect the sustainable use of steel.

Figure 1 below shows six sequential stages of the material sustainability cycle (MSC)[1]. Between each sequential pair, standards are needed to effectively communicate from one stage to the next. Standards act like a Rosetta Stone ensuring that all parties understand and agree to generated information, the protocols and technical/scientific basis used to generate data, and data accuracy and precision. The standards that link across different elements are often the same – products are manufactured to meet certain engineered performance standards, which are the same standards used by specifiers, designers, and engineers. Therefore, multiple industrial sectors are stakeholders in this research.

[1] BEES (Building for Environmental and Economic Sustainability),http://www.nist.gov/el/economics/BEESSoftware.cfm

The consequences of not having service life prediction capability for these materials are manifold. The total costs of repairing/replacing the US infrastructure is estimated to exceed $2 trillion[2,3], and the American Society of Civil Engineers (ASCE) has recommended that "as infrastructure is built or rehabilitated, life cycle cost analysis should be performed"[4], which will not be performed in sustainable manner without SLP. The Administration has stated that building a world-class physical infrastructure is one of its top priorities for innovation[5,6]. A technology gap in the long-term strategic plan for highways is an inability to ensure sustainable performance of concrete in the short and long term[7]. Service life prediction of polymer composites have been clearly seen as a major national need[8,9]. The Administration's *Blueprint for a Clean Energy Future* [10] calls for the development of more efficient cars and trucks by making investments in polymer composites for lightweighting. New, nano-enabled fiber-reinforced polymer composites can help rejuvenate

---

2 *Report Card for America's Infrastructure*, American Society of Civil Engineers, 2012. (www.asce.org)
3 *Investment in Federal Facilities*, National Research Council (2006).
4 ASCE 2009 Infrastructure Report Card (http://www.infrastructurereportcard.org)
5 *A Strategy for American Innovation: Driving Towards Sustainable Growth and Quality Jobs*, http://www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation/
6 *OSTP/OMB Science and Technology Priorities for the FY 2012 Budget*, 2010, http://www.whitehouse.gov/sites/default/files/microsites/ostp/fy12-budget-guidance-memo.pdf
7 "Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development," FHWA-HRT-08-068, Federal Highway Administration (July 2008)
8 *Going to Extremes: Meeting the Emerging Demand for Durable Polymer Matrix Composites*, Committee on Durability/Life Prediction of Polymer Matrix Composites in Extreme Environments, National Research Council, 2005.
9 Vision 2020 Chemical Industry of The Future: Technology Roadmap for Materials: http://www.chemicalvision2020.org/pdfs/materials_tech_roadmap.pdf
10 *Blueprint For a Clean Energy Future,* http://www.whtehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf

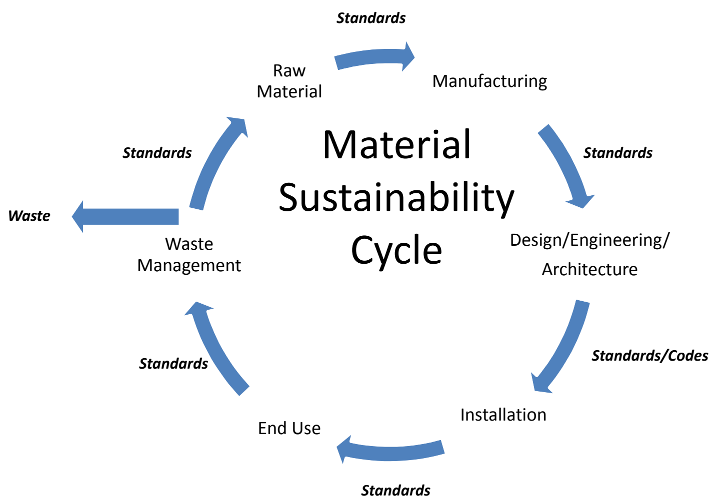


Figure 1: Illustration of the sustainability cycle for materials in the US

US manufacturing, but the lack of service life prediction capability for this class of materials was a barrier identified by industry to their widespread use[11]. The addition of nano-fillers to polymeric matrices greatly improves product performance, but has raised environmental, health and safety issues with the release of these nanoparticles over time.[12,13] The durability of filled polymers, which are non-structural polymer composites, plays a key role in important national problems. Plastic piping is expected to be used in increasing volumes as replacements, as pipe leaks and breaks in municipal water/sewage systems have steadily increased in recent years[14]. The yearly global market in sealants and adhesives is approximately $40B, and having standards that accurately measure their durability is an outstanding problem in their sustainable use [15]. The aging of polymeric electric cable insulation in nuclear power plants is a national problem, affecting all of the existing fleet of 104 US nuclear reactors[16].

**Why is it hard to solve?** Polymer composites and concrete are inherently complex, multi-phase systems. Both are made from a variety of feedstocks, including industrial by-product materials. Unexpected variations in performance mandate careful material characterization. Specifying short term properties is hard since not all the required measurement techniques have been developed or standardized. The degradation of these systems involves chemical, physical, and mechanical component and environmental interactions that operate over wide length/time scales.

---

[11] The New Steel? Enabling the Carbon Nanomaterials Revolution: Markets, Metrology and Scale-Up http://www.nist.gov/cnst/thenewsteel.cfm

[12] Congressional Research Service, Nanotechnology and Environmental, Health, and Safety: Issues for Consideration, John F. Sargent Jr., January 20, 2011, *http://www.fas.org/sgp/crs/misc/RL34614.pdf*.

[13] *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials* (2011), Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials; National Research Council

[14] *Sustainable water infrastructure*, US Environmental Protection Agency, http://water.epa.gov/infrastructure/sustain/index.cfm

[15] ASTM and RILEM, Durability of Building and Construction Sealants and Adhesives, STP 1514 (2010).

[16] Essential Elements of an Electric Cable Condition Monitoring Program US NRC NUREG/CR-7000 BNL-NUREG-90318-2009 (http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7000/cr7000.pdf)

**How is it solved today, and by whom?** The measurement science problems that need to be solved in order to have standards that can enable service life prediction for materials used in infrastructure and manufacturing have not currently been solved. For concrete, industry practice documents like ACI-365.1R-00[17] and certain computer models like Life-365[18] are guides and tools for estimating service life based on an over-simplified scientific basis. More comprehensive service life computer models, such as STADIUM[19] in Canada, do exist but in all cases, the initial condition is a properly placed, finished, and cured concrete element, which assumes adequate early-age performance[20]. The MIT Concrete Sustainability Hub, funded by the cement and concrete industry, is the major US academic player in modeling concrete sustainability. The Nanocem consortium in Europe is active in service life of concrete issues, along with the European and Japanese cement industry.

US industry relies on qualitative, long-term field exposure tests for service life prediction of polymer composites but the ability to generate repeatable and reproducible results has been a major weakness of this methodology. Underwriter's Laboratories uses its thermal aging test, UL 746B, to approve 20B polymer products per year, but does not take into account the effects of relative humidity, radiation, and mechanical load. The academic centers and industrial labs working in polymer nanocomposites do not typically work in service life prediction issues. The European Union and European industry funds research in the modeling and manufacture of nano-enabled fiber-reinforced polymer composites.

**Why NIST?** Measurement science research that results in standards used to classify and specify materials used in infrastructure, construction, and manufacturing is closely aligned with the NIST Engineering Laboratory (EL) Strategic Goal of Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure. This program supports EL's mission[21], follows EL's vision[22], and relies on one of the EL core competencies[23] of durability and service life prediction of materials. NIST/EL is internationally known for the assessment of performance, durability and service life prediction of polymer composites and concrete, and has the instrumentation, computer hardware and software, and expert personnel to be able to carry out this program. Industry stakeholders partner with the program in various CRADA-based consortia and road mapping activities, and state and federal agencies employ the program's unique capabilities to support their mission/agency goals.

---

[17] "Service Life Prediction – State-of-the-Art Report," ACI 365.1R-00, American Concrete Institute
[18] http://www.life-365.org
[19] http://www.simcotechnologies.com/Stadium/Introduction.aspx
[20] "Measurement Science Roadmap for Workability of Cementitious Materials" held at NIST on March 18, 2011 – NIST Technical note under review**update**
[21] EL's mission is "To promote U.S. innovation and industrial competitiveness in areas of critical national priority by anticipating and meeting the measurement science and standards needs for technology-intensive manufacturing, construction, and cyber-physical systems in ways that enhance economic prosperity and improve the quality of life."
[22] EL's vision is "To be the source for creating critical solution-enabling measurement science, and critical technical contributions underpinning emerging standards, codes, and regulations that are used by the U.S. manufacturing, construction, and infrastructure industries to strengthen leadership in domestic and international markets."
[23] EL core competencies: Intelligent sensing, control, processes, and automation for cyber-physical systems; Systems integration, engineering, and processes for cyber-physical systems; Energy efficient and intelligent operation of buildings with healthy indoor environments; Sustainability, durability and service life prediction of building and infrastructure materials; Fire protection and fire dynamics within buildings and communities; Resilience and reliability of structures under multi-hazards.

**What is the new technical idea?** The new technical idea is to couple advances in analytical instrumentation, controlled multi-factor exposure in the laboratory, new physical/chemical tests, and modeling and computational materials science to measure and predict the service life performance of materials to enable critical and sustainable end-use applications in infrastructure and manufacturing. This integrated approach will allow the measurement science to be developed that will provide the technical basis for new and improved standards that will support service life prediction for these complex materials.

**Why can we succeed now?** Engineers and designers regularly push the design limits of materials, such as in nano-filled polymers, nano-enabled fiber reinforced polymer composites, and increasing use of industrial by-products in concrete, which forces changes in existing standards and codes to enable sustainable use. Significant advances have occurred in recent years in analytical instrumentation, the ability to control exposure environments, and software and hardware for modeling material lifetime performance, much of which pioneered by this program. NIST has the joint experimental and modeling expertise to solve the hard problems associated with service life prediction and sustainable material performance. NIST has strong partnerships with industry and the standards community. NIST's participation, and in many cases leadership, in technical standards committees coupled with active end-user engagement via consortia and road mapping workshops ensures that its technical ability to meet measurement science needs will result in effective technology transfer to industrial end-users via new and improved standards.

**What is the research plan?** There are two thrusts in this research plan: service life prediction of polymer composites and service life prediction of concrete. The path to the overall goal of service life prediction of structural polymer composites is divided into three levels (see Fig. 2): unfilled polymers, filled polymers, and structural polymer composites, which contain fibers and fillers. The unfilled polymer level was finished some years ago, and is the basis for the higher levels. The work on filled polymers is dealing with important new degradation mechanisms like mechanical movement, surface damage, electrical aging, and dispersion of fillers. When the fillers are nano-size, then their release during degradation becomes an important environmental-health-safety issue to be understood, and is also an active process in structural polymer

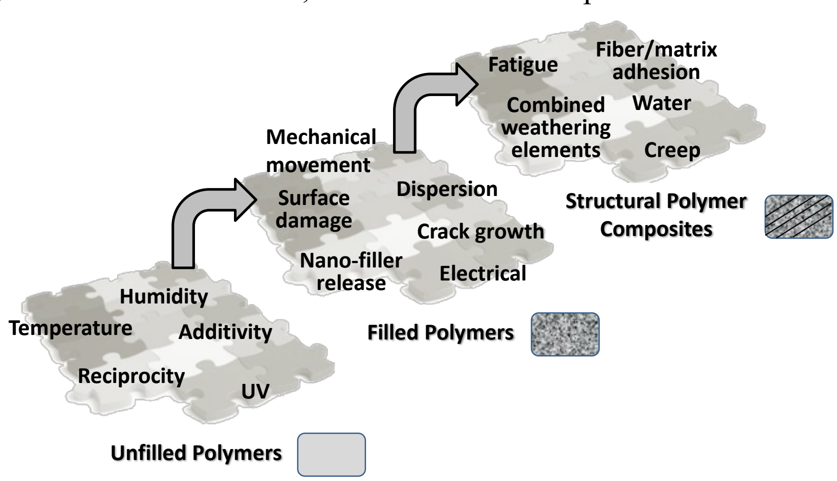


Figure 2: Structure of Service Life Prediction of Polymer Composites research

composites with nanofillers. Inroads are now being made into the third level, based on previous research, on the effect on polymer composites of fatigue, water, adhesion between fiber and polymer matrix at the interface, and combinations of environmental factors. At each level, partners are identified who help the work progress and at the same time help identify and solve important national problems.

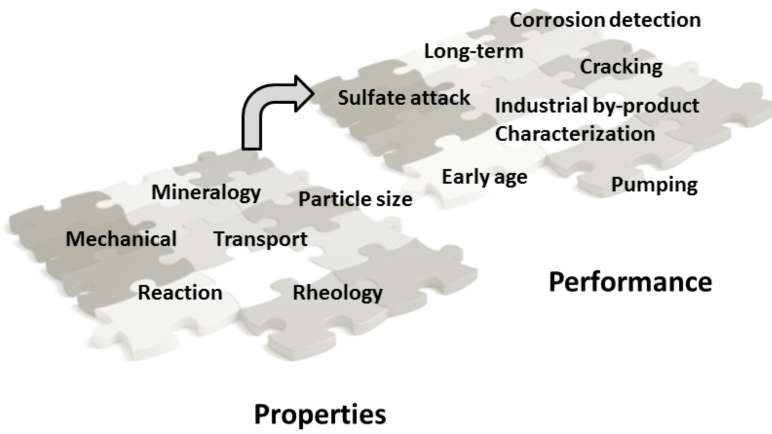


Figure 3: Structure of Service Life Prediction of Concrete research

Figure 3 shows the overall structure of the service life prediction of concrete thrust, where its two levels reflect properties and performance. Previous work, some of it still on-going, concentrated on being able to characterize, measure and predict, with computational materials science models, various material properties of concrete at the cement paste, mortar, and concrete scales. This work has given the basis for looking at performance, in particular service life prediction, which encompasses both early-age and long-term performance, since concrete failures occur from mixing and placement to late-age degradation.

Characterization, performance measurement techniques, accelerated durability tests, and modeling will be used to achieve program goals. Characterization means measuring what the materials are made out of at the most relevant length scale. Measurement techniques mean quantitative measurements of properties such as viscoelastic mechanical parameters, shrinkage or expansion as a function of temperature or humidity, and surface damage under nanoindentation, among others. Accelerated durability tests can include carefully controlling temperature, humidity, solar exposure, mechanical load, or specimen geometry in order to make degradation mechanisms proceed faster and produce valid results in less time. Modeling is used, from the computational materials science-type models using high-powered computers to simple parameterized equations, to understand measurements, suggest new measurements, and transform performance measurements into performance predictions. Incorporating research results into standards is the final step in the research plan. What is supplied to the standards committees can be in several forms: (a) standard reference data or materials, (b) new draft standard performance test methods, and (c) validation of the use and uncertainty estimation of a simpler tool by more sophisticated measurements. The exact standards committees the program works with are carefully chosen so as to maximize the impact of the program's research based on national needs and industry input via published research need roadmaps.

**How will teamwork be ensured?** The Sustainable Engineered Materials program is made up primarily of members of EL's Polymeric and Inorganic Materials Groups, along with a NIST Fellow. There is a single principal investigator assigned for each of five projects who is accountable for the performance of the project. There is a team assigned to each project as well, who interact regularly on project tasks. Each team member is the best qualified for the project(s) to which they are assigned. All the project leaders are accountable to the program manager, who reviews their progress periodically.

**Accomplishments and Impact:**

**R&D Impacts**: The measurement science results produced by the Sustainable Engineered Materials program must be first published in a peer-reviewed journal in order for standards committees and other stakeholders to accept this work as being scientifically credible and thereby valid for use. Publication also builds the scientific stature of the program so that our results are respected and cited, increasing the program impacts on the Nation, and facilitates the recruiting of personnel and other agency projects related to program goals. Thus, the publishing strategy of the program is two-fold. We publish our research in high-impact factor journals that are read and cited by our scientific peers in order to obtain stringent peer review and validation of our work. We also publish in journals that are extensively read by our stakeholders. There is a strong overlap between these two classes of journals, but there are some differences. In the table below, the main journals that the program uses are separated into those that are more widely read by our stakeholders (**Stakeholder audience**) and a class that tends to be more widely read by

| Journal | No. papers since 2006 | 5 year citation factor (up to 2011) | No. papers accepted but not yet published | No. papers though WERB in FY2013 |
|---|---|---|---|---|
| **Stakeholder audience** | | | | |
| Journal of Coatings Technology/Research | 6 | 1.256 | | 1 |
| Polymer Engineering and Science | 2 | 1.654 | | |
| Polymer Degradation and Stability | 11 | 3.069 | | |
| Journal of Applied Polymer Science | 2 | 1.413 | | |
| Review of Scientific Instruments | 2 | 1.499 | | 1 |
| Concrete International | 12 | ** | 1 | |
| ASCE Journal of Materials in Civil Eng. | 7 | 1.037 | 1 | |
| ACI Materials Journal | 7 | 1.283 | | |
| Cement and Concrete Composites | 14 | 2.726 | | |
| Sub-total | 63 | | | |
| **Research audience** | | | | |
| Journal of Nanosci./Nanotech. | 1 | 1.574 | | |
| Journal of Adhesion | 2 | 1.144 | | |
| Langmuir | 1 | 4.514 | | |
| Macromolecules | 1 | 5.030 | | |
| Cement/Concrete Research | 14 | 3.282 | | 2 |
| Physical Review E | 2 | 2.261 | | 1 |
| Materials and Structures | 3 | 1.507 | | |
| Journal of the American Ceramic Society | 6 | 2.383 | 1 | 1 |
| Modeling and Simul. Mater. Sci./Eng. | 2 | 1.780 | | |
| Powder Technology | 6 | 2.221 | | 1 |
| Sub-total | 39 | | | |
| Total number of papers | 102 | | 3 | 7 |

**Concrete International has a circulation of 20,000 concrete professionals fellow scientists in our fields **(Research audience**). The table covers publications between 2006 and the present. It can be seen that the program's publication in the main journals is more in the stakeholder than the research audience journals. In addition, there were approximately 150 other papers published in various journals and conference proceedings over the same time period (not shown). These papers often describe work done for outside agencies, which may tend to be published in other journals of interest to that agency. Conference proceedings can be quite useful and attract a large readership.

**Technology Transfer Impacts**: The technical areas being worked on in this program have been jointly identified with industry and other end-users, hence the research, tools, and standards produced meet identified needs and hence have a high probability of being adopted and used. These technology transfer impacts are carried out through participation in standards committees, individual CRADAs, CRADA-based consortia, interaction with other government agencies, web dissemination of tools, and publication.

Many specific stakeholders and end-users from the broad communities of infrastructure and manufacturing have expressed keen interest in the program via intellectual and/or financial collaboration with individual projects: electric power industry and utilities, construction and infrastructure materials specifiers, electrical cable manufacturers and users/owners, coatings and plastics suppliers, automotive industry, aerospace industry, state Departments of Transportation, Nuclear Regulatory Commission, American Association of State Highway Transportation Officials (AASHTO), Federal Highway Administration, Department of Energy, Gas Technology Institute (GTI), Adhesive and Sealant Council (ASC), and Plastic Pipes Institute (PPI).

**Technology Transfer Outcomes in FY13**

<u>Project: Surface Damage of Polymer Nanocomposites</u>

- Design and fabrication of a new UV exposure cell to improve sampling and data collection for nanoparticle release measurement. This device will be included in the proposed ASTM photo-induced particle release test methods.
- Development of a laser scanning confocal microscopy measurement protocol for quantifying released metal-oxide nanoparticles on the surface of polymer nanocomposites after mechanical scratching or abrasion.
- Completion of a round robin experiment to develop methodology and standard tests for quantifying the release of nanoparticles by weathering, which was a joint project with the European Union NanoGEM and Polynanotox projects.
- Completion of a work plan for methods development and a state of the science analysis of nanofiller release in the Inter-laboratory Testing Group of the NanoRelease Project, which is a multi-stakeholder project led by government (NIST, CPSC, EPA), industry, and consumer and labor organizations under the non-profit International Life Sciences Institute (ILSI).

<u>Project: Service Life Prediction of Filled Polymers</u>

- Report on "Polymer Piping Codes and Standards for Nuclear Power Plants: Current Status and Recommendations for Future Codes and Standards Development", through the Nuclear Energy Standards Coordination Cooperative (NESCC) Polymer Piping Task Group, chaired by program personnel. The report was adopted by ASME as a component of their code, standards, and research roadmap for regulatory acceptance of plastic pipe in both nuclear and non-nuclear applications.

- Archival publication on the development, testing and implementation of a commercial NIST SPHERE-based testing device for sealant durability, incorporating radiation, temperature, moisture, and mechanical movement.
- Establishment of a strategic partnership with Underwriters Laboratories (UL) focused on initiating changes to the long-established UL 746 standard for long-term thermal aging of plastics. This has resulted in balloting of new UL standards relating to the 746 process (28B products/year have UL stamp), changes to the UL plastics database (88,000 plastics tested), and the purchase of a commercial version of the NIST SPHERE device by UL to evaluate for future standards development.
- Novel advanced measurement tools for polymeric insulation in electrical cables by combining spectroscopic, microscopic, and electrical measurement techniques for characterization of polymer degradation under exposure to relevant environmental stressors.

Project: Early-Age Performance of Concrete

- All materials for a new Standard Reference Material for mortar rheology were provided to Measurement Service Division for packaging**.**
- Precision and accuracy qualification criteria on XRF analysis for two different methods using portland cements was provided to the ASTM C01.23 subcommittee. This is an essential step to ensure that a standard test method "X-ray Fluorescence Analysis of Hydraulic Cement" will be accepted by ASTM and used by all cement manufacturers.

Project: Long Term Performance of Concrete

- NIST-proposed changes approved by ASTM for ASTM C1585-13 *Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes*.
- American Concrete Institute (ACI) published *ACI (308-213)R-13---Report on Internally Cured Concrete using Prewetted Absorptive Lightweight Aggregate*, co-authored by project PI. Internal curing is of great benefit to both the early-age and long term performance of concrete structures.

Project: Service Life of Nano-enabled Fiber-Reinforced Polymer (NeFRP) Composites

- This project was new in FY2013 so is still developing measurement techniques and is not yet at the technology transfer stage**.**

**Potential Technology Transfer Impacts**:

- **Service Life Prediction of Filled Polymers - FY12**: New standards, involving mechanical movement, have been adopted and are being used by major sealant manufacturers.
    - ASTM 1735-11 *Test Method for Measuring the Time-Dependent Modulus of Sealants Using Stress Relaxation*
    - ASTM 1589-12 *Standard Practice for Outdoor Weathering of Construction Seals and Sealants* has passed. It is the first ASTM C24 standard to recognize and incorporate fatigue as a significant factor in the property changes over time of a filled polymer sealant material and includes NIST generated data and archival journal publications.
- **Service Life Prediction of Filled Polymers - FY12-13:** The US Nuclear Regulatory Commission (NRC) has asked NIST to develop condition monitoring methods for aging electrical cables in nuclear power plants as a basis for standardized safety and replacement evaluation in all US nuclear power plants. The NIST/NESCC report on *Electrical Cable Aging and Condition Monitoring Codes and Standards*, has received the attention of Institute of Electrical and Electronics Engineer (IEEE SC2 13-01) and the Insulated Conductors Committee, a technical committee of the IEEE within the Power and Energy Society.
- **Service Life Prediction of Filled Polymers - FY13: The NESCC report on** Polymer Pipe Codes and Standards, authored by the NESCC task group chaired by program personnel, is being used ASME to build their Roadmap for codes and research. By request of the NESCC participants, especially DOE and NRC, the NIST Chair has worked with ASME and NRC representatives to develop a single roadmap to achieve short-term and long-term goals for HDPE acceptance into the regulation.
- **Long Term Performance of Concrete - FY12**: ASTM C1760-12 *Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete* and ASTM C1585 Sorptivity Test Method, approved in FY12. These two documents standardize two key transport property measurements that are used in service life prediction.
- **Early Age Performance of Concrete - FY12**: ASTM C1749-2012: *Standard Guide for Measurement of the Rheological Properties of Hydraulic Cementitious Paste Using a Rotational Rheometer*. First of a suite of standards that will allow the quantitative use of calibrated concrete rheometers.
- **Long Term Performance of Concrete - FY12**: ASTM C1761- 2012 *Standard Specification for Lightweight Aggregates for Internal Curing of Concrete*. Standardizes how to cure concrete to achieve low-cracking potential, giving more durable long-term performance.
- **Early Age Performance of Concrete - FY12**: *NESCC Concrete Task Group (CTG) Concrete Codes and Standards for Nuclear Power Plants: Recommendations for Future Development* (2011). The recommendations of this report have started to be implemented by the American Concrete Institute.
- **Long Term Performance of Concrete - FY11**: VERDICT technology developed at NIST. This technology is a completely different way of enabling significant increases

in the lifetime of concrete using a NIST discovery that makes concrete resistant to attack by aggressive, degrading chemicals like road salts.

**Realized Technology Transfer Impacts**

- **Early Age Performance of Concrete – FY11**: The program developed ASTM C1365 - 06 *Standard Test Method for Determination of the Proportion of Phases in Portland Cement and Portland-Cement Clinker Using X-Ray Powder Diffraction Analysis* and updated it. It is being used extensively in the US and Canada. NIST Standard Reference Materials SRM 2686/7/8 were developed by the program to support the use of this standard.
- **Early Age Performance of Concrete – FY10**: NIST Standard Reference Materials SRM 114Q/46H have been issued and are sold and used in the US, Canada, and Europe. These are cements used by laboratories for validating their use of two critical quality control tests for cement production and use involving particle fineness for short-term performance. Their combined sales of rank 3rd overall at NIST in the number of units sold.
- **Service Life Prediction of Filled Polymers - FY12**: All the weathering standards for sealants and building joints in ASTM C24 Building Joints and Sealants have been changed to include mechanical movement. "Weathering" in this committee now is defined as having a mechanical movement component, a key variable in service life prediction, solely due to the measurement science research of this program.
- **Early Age Performance of Concrete – FY11**: ASTM C1738 *Standard Practice for High-Shear Mixing of Hydraulic Cement Pastes*. This is foundational to the suite of standards being built up by the program for using rheology to measure concrete workability.
- **Early Age Performance of Concrete – FY11:** NIST Standard Reference Material #2492 *Bingham Paste Mixture for Rheological Measurements*. This is the first of three standard reference materials that will be produced to support suite of standards being built up by the program for using rheology to measure concrete workability.
- **Program Result – FY10**: NIST measurement science revealed that the time-dependent properties of the adhesive used in the Boston Harbor "Big Dig" disaster were neither considered nor sufficient to withstand long-term loading, which led to the new AASHTO standard "*Standard Test Method for Evaluation of Adhesive Anchors in Concrete Under Sustained Loading Conditions",* and to changes in the International Code Council (ICC) Evaluation Service AC308 document (http://www.icc-es.org/criteria/pdf_files/ac308.pdf) which now requires sustained loading testing for anchors adhered to concrete.
- **Program Result – FY10**: The Justice Department asked NIST to solve the problem of why certain polymeric body armor was failing. NIST measurement science determined that wearing conditions were prematurely degrading the armor polymer. The protocols developed formed the basis of a new National Institute of Justice body armor service life standard 0101.06.
- **Long Term Performance of Concrete – FY09**: ASTM C1698 *Standard Test Method for Autogenous Strain of Cement Paste and Mortar*. This is a key test method

for indicating the tendency for a concrete to crack at early-age during curing, hence can be used as a screening test.

**Recognition of EL:** There have been many articles in industry trade journals such as *Concrete Producer*, *Constructor*, *Stone Sand and Gravel Review*, *Legacy*, *Adhesives Age*, and *Journal of Coating Technology*, covering program research. In addition, articles about program research have appeared in *R&D Magazine*, *Engineering News Record*, *Concrete International*, *MIT Technology Review*, the *New York Times*, and the *Baltimore Sun*.

<u>Awards that have been given to program personnel since 2007, in reverse chronological order</u>:

Paul Stutzman, ASTM Award of Merit, Fellow of ASTM C01, 2013.
Jeffrey Bullard, American Ceramic Society Cements Division, Stephen Brunauer Award, 2012.
Jeffrey Bullard, Engineering Laboratory Communicator's Award, 2012.
Stephanie Watson, NIST Safety Award, 2012.
Dale Bentz, Best Paper Award, Magazine of Concrete Research, 2012.
Dale Bentz, Honorary member of ASTM C01 Cements committee, 2012.
Edward Garboczi, Della Roy Lecture, American Ceramic Society Cements Division, 2012.
Tinh Nguyen and Li-piin Sung, NIST Bronze Medal, 2011.
Tinh Nguyen, American Coatings Association, Joseph J. Mattiello Award, 2010; Robert L. Patrick Fellow of the Adhesion Society, 2010.
Joannie Chin, Department of Commerce Gold Medal, 2010.
Aaron Forster, Adhesion Society Outstanding Young Adhesion Technologist, 2010.
Edward Garboczi, Nicos Martys, Jeffrey Bullard, and Dale Bentz, Department of Commerce Silver Medal, 2009.
Walter Rossiter, ASTM S03 Award of Excellence, 2009.
Edward Garboczi, NIST Fellow, 2009.
Christopher White, Department of Commerce, Bronze Medal 2009.
Chris White and Walt Rossiter, ASTM E54 Distinguished Service Award, 2009.
Dale Bentz and Kenneth Snyder, Department of Commerce Bronze Medal, 2009.
Clarissa Ferraris, American Concrete Institute D.L. Bloem Distinguished Service Award, 2008.
Walter Rossiter, ASTM D08 William C. Cullen Award, 2008.
Paul Stutzman, ASTM P.H. Bates Award, 2008; Department of Commerce Bronze Award, 2007.
Dale Bentz, Expanded Shale, Clay & Slate Institute Frank G. Erskine Award. 2007; American Concrete Institute Wason Medal for Materials, 2007.