2009 BFRL Project Description

Project Title: Fire Resistive Materials for Structural Steel

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BFRL Program: Measurement Science for Structural Performance Under Multi-Hazards

Objective: To provide the measurement science infrastructure for the performance assessment and optimization of fire resistive materials (FRMs) .

Problem:

What is the problem?

The performance of the fire resistive materials (specifically their dislodging upon impact from the debris field) has been identified as a key factor in the collapse of the WTC twin towers. During the course of the WTC investigation, it became clear that the thermophysical and adhesion properties of these materials (necessary for modeling and performance prediction) were not available, particularly at high temperatures. Until the present study, a fundamental material science-based approach had never before been applied to the characterization of the microstructure and performance properties of these materials. Providing this measurement science infrastructure for FRMs will ultimately allow the prediction of their performance during ASTM E119 testing and real fire exposures, as well as the adoption of performance-based code requirements founded in science and engineering. The industry would welcome the development of these computational tools that could result in significant cost savings due to a reduction in the physical testing of inferior materials and systems.

Why is it hard to solve?

Fire resistive materials change dramatically during a high temperature exposure (fire), including mass losses, dimensional changes (shrinkage and expansions), chemical reactions, and microstructural modifications leading to dramatic changes in both thermal and mechanical properties. For adhesion, different tests are required for laboratory screening and quality assurance under field conditions.

How is it solved today, and by whom?

Thermal properties are only provided at room temperature and adhesion is only quantified in the field, using the ASTM E736 “mayonnaise cap” strength based tests. The results include the skill of the operator and do not give a fundamental material property. No consideration is

given to these properties at higher temperatures. The materials science of these materials has been grossly neglected by both the academic and industrial research communities.

Why NIST?

Developing an appropriate measurement science infrastructure for FRMs has been identified as an authenticated measurement need by NIST. NIST has both the necessary technical expertise to develop the measurement science to support the critically needed ASTM test methods and code changes and the industrial contacts (materials suppliers, testing laboratories), to promote their implementation and adoption by the construction community.

Approach:

What is the new technical idea?

The research in this project has been focused on four new technical ideas:

1) a fracture mechanics approach to adhesion,

New test methods based on a foundation of well established fracture mechanics would allow the adhesion to be measured without any contribution of the skill of the operator performing the test. Additionally, the results will be able to used as inputs to physics-based strucural simulations, a fundamental component of performance based standard development. These test methods will enable manufactures to quickly and accurately evaluate the adhesion of the Spray-Applied Fire Resistive Materials (SFRM). Additionally, a field test with a different geometry can be related to the peel test developed for the manufacturer's qualification procedure. These test methods will be proven at room temperature and expanded to evaluate the adhesion at elevated temperatures.

2) A new experimental technique (slug calorimeter) for measurement of high temperature thermal conductivity,

In collaboration with division 863, a thermal capacitance (slug) calorimeter has been designed, built, and extensively employed to evaluate the thermal conductivity of FRMs from room temperature to 700 ºC.

3) A proposed methodology for characterization of thermophysical properties of FRMs,

In collaboration with division 866, a detailed methodology for characterizing FRMs with respect to the inputs (thermal conductivity, density, heat capacity, heats of reaction) required for computational modeling of thermal performance has been developed.

*4) Three-dimensional microstructure characterization via x-ray microtomo*graphy *(followed by computational materials science to predict thermal properties for example)*

Originally, microstructural characterization was performed in collaboration with the Penn State Center for Quantitative Imaging. In FY 2008, BFRL purchased its own 3-D x-ray microtomography unit. Already, three materials suppliers are interested in collaborating with NIST to examine the 3-D microstructure of their intumescent coating products.

Why can we succeed now?

The new measurement methods have been developed and are either now standardized or soon to be proposed for standardization. The efforts to adapt computational tools from previous BFRL research (protective clothing for firefighters) to fire performance of FRM/steel systems will provide a simple but powerful computational tool for material developers and engineers.

What is the research plan?

Three items from the perspective of thermal performance will be completed finishing the thermal performance component of this project. These are the completion of an ASTM interlaboratory study (ILS) to establish a multi-laboratory precision for the E 2584 standard practice, the testing of a bare steel column at UL laboratories to provide assurance of parametric values being employed in the computational modeling of the fire performance of structural steel protected by an FRM, and the presentation of the validated computational tool for thermal performance to the industry. The ILS was initiated this spring, involving three different representative FRMs and potentially ten different laboratories. NIST is coordinating the study and will be responsible for the collection and statistical analysis of all of the results. The purchase order for the UL testing is currently in NIST procurement and it is envisioned that the testing will be conducted in the summer/fall of 2008. These testing results will be used to better understand the modeling of the thermal performance of FRM-protected steel in a test furnace and ultimately in a real fire. Once validated for the bare steel and FRM-protected steel cases, the computational tool will be presented and promoted to the industry.

It is envisioned that two ASTM standards will be initiated within the E6.21 sub-committee. These two standards will be for the fracture mechanics based peel test method for the manufacturers to develop new SFRM materials and the fracture mechanics based field quality control test method based on a magnetically attached adhesion test method. Also the existing thermal furnace will be modified to perform preliminary adhesion performance at elevated temperatures. As this data is collected it will be collected and made available to the public through web-based databases.

The effect of elevated temperatures on the adhesion performance of SFRM will be evaluated.

The effect of preconditioning, (example: humidity conditions) on the adhesion performance of the SFRM will be performed.

Recent Results:

Prasad, K.R., Bentz, D.P., "Thermal Performance of FRMs II. A Multi-Layer One-Dimensional Heat Transfer Model for Fire Resistive Materials Protecting a Substrate," NISTIR **7482**, 02/08. (Output)

Bentz, D.P., Prasad, K.R., "Thermal Performance of Fire Resistive Materials I. Characterization with Respect to Thermal Performance Models," NISTIR **7401**, 2007. (Output)

Slug calorimeter commercialized in 2008 by Anter Corporation; Southwest Research Institute and Intertek have ongoing research projects to establish in-house slug testing capabilities. (Impact)

C.C. White, K.T. Tan,and D.L. Hunston *Adhesion of fire resistive materials to structural steel.*, Proceedings of the 31th Annual Meeting of the Adhesion Society, Inc., Feb. 17-20, 2008, Austin, TX, G. Anderson (Ed.), pp. 379-381. (Output)

C.C. White K.T. Tan, and D.L. Hunston *Adhesion test method for sprayed fire resistant materials,* Proceedings of the American Chemical Society: Polymeric Materials: Science and Engineering, 98, 167-168 (2008). (Output)

Standards and Codes:
ASTM E2584 "Standard Practice for Thermal Conductivity of Materials Using a Thermal Capacitance (Slug) Calorimeter" published by ASTM in November, 2007. (Outcome)

Coordinating ongoing ILS to develop a multi-laboratory precision statement for E2584
Drafting two standards on adhesion testing (lab and field) to propose to ASTM E06.21. (Outcome)