Protecting Steel at High Temperatures

BY DALE P. BENTZ AND CHRISTOPHER C. WHITE, PH.D.

NIST researchers are developing new ways of testing and measuring fire-resistive materials.

FIRE-RESISTIVE MATERIALS (FRMS) perform a critical, life-saving function in buildings and structures, yet have received surprisingly little attention from the scientific community. At the National Institute of Standards and Technology (NIST), our goals have been to provide the measurement science infrastructure for assessing FRM performance and optimizing the abilities of these materials to protect steel structures during fires.

Some examples of FRMs are low-density gypsum or cement-based materials containing fibers or lightweight fillers. Other examples include intumescent coatings that may expand up to 40 times in thickness during exposure to a fire (see Figure 1).

The two major performance objectives of an FRM are to provide thermal protection (insulation) for the steel that it is safeguarding and to remain in place prior to and during an exposure to fire. With these objectives in mind, NIST's Fire Resistant Materials for Structural Steel project has focused on the measurement of the thermal and adhesion properties of these materials. As a validation of this research's high relevance to industry, we recently completed a successful three-year consortium entitled "Performance Assessment and Optimization of Fire Resistive Materials," with industrial participation from the American Iron and Steel Institute, Anter Corporation, Barrier Dynamics LLC, Isolatek International, Lightconcrete LLC, PPG, and W.R. Grace & Co.

One major accomplishment of the FRM project has been the drafting and subsequent approval (in September 2007) of a new test method that has been published by the ASTM International standards organization as ASTM E2584. This new test method measures the thermal conductivity of these materials at elevated temperatures using a methodology developed at NIST. This technology has been commercialized by a U.S. manufacturer of thermal testing equipment and the NIST experimental setup has been duplicated by several independent testing laboratories around the world. Currently NIST is coordinating an interlaboratory study to establish a multi-laboratory precision statement for the standard practice, with nine participants from the U.S. and Canada.

Figure 1. Commercial intumescent coating specimen prior to (left) and after testing in the slug calorimeter high-temperature experimental setup at NIST.

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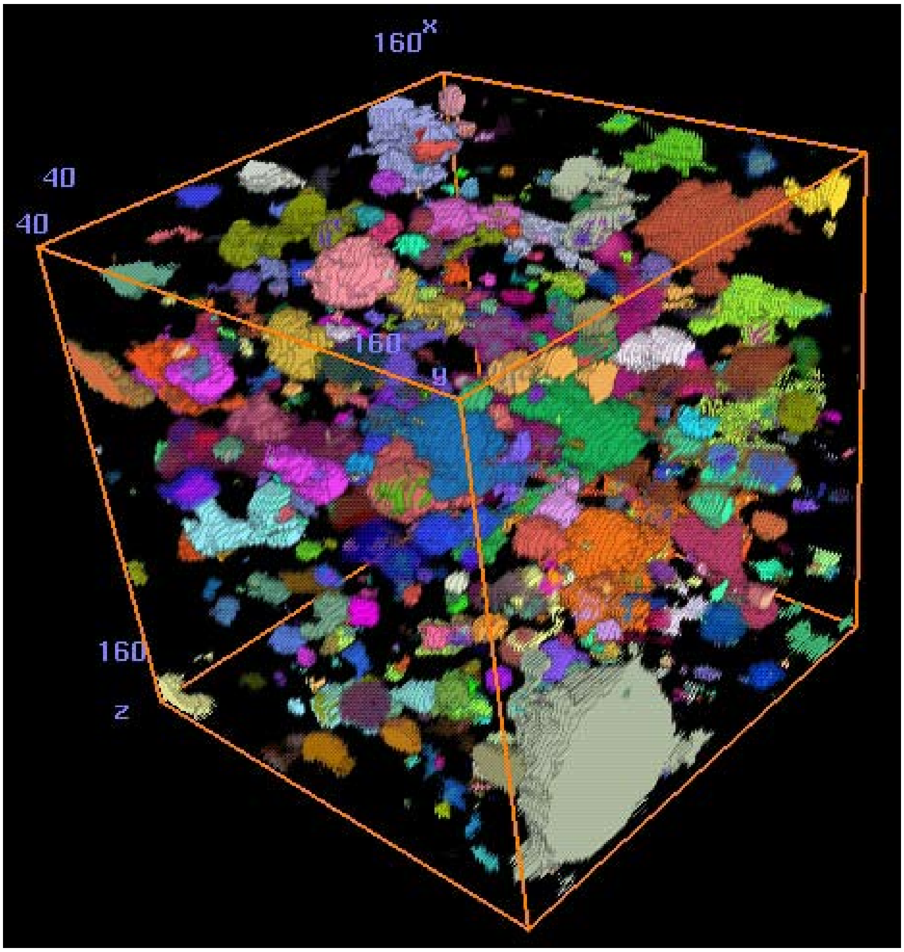

Figure 2. False color rendering of the individual pores in a gypsum-based fire-resistive material (FRM). Dimensions are 120 by 120 by 120 voxels (3D pixels). Voxel dimensions were 0.0273 mm in the x and y directions and 0.0361 mm in the z direction.

Other Results

Another significant accomplishment has been the development of a quantitative methodology for characterizing FRMs with respect to inputs for thermal performance models. We have recommended methodologies for obtaining thermophysical properties needed for computational thermal models, including density, specific heat capacity, thermal conductivity, heats of reactions and phase changes, and total emissivity.

We also have demonstrated x-ray microtomography as a powerful technique for characterizing the 3D microstructure of FRMs (see Figure 2). In this area we have employed the computational tool known as finite difference algorithms. Using this tool we accurately compute the thermal conductivity of FRMs as a function of temperature, based on a 3D microstructural representation of the porous FRM obtained using x-ray microtomography.

Finally, we have used fire testing of a bare steel column at a national testing laboratory to establish the appropriate viewing factor to use for radiative transfer in computational thermal models. These tests showed that a viewing (safety) factor of about 0.45 was necessary to reduce the computed radiative contribution to energy transfer from the fire to the steel, in order to fit the measured temperature rise data for the steel column. This value is in reasonable agreement with factors determined previously for European test furnaces.

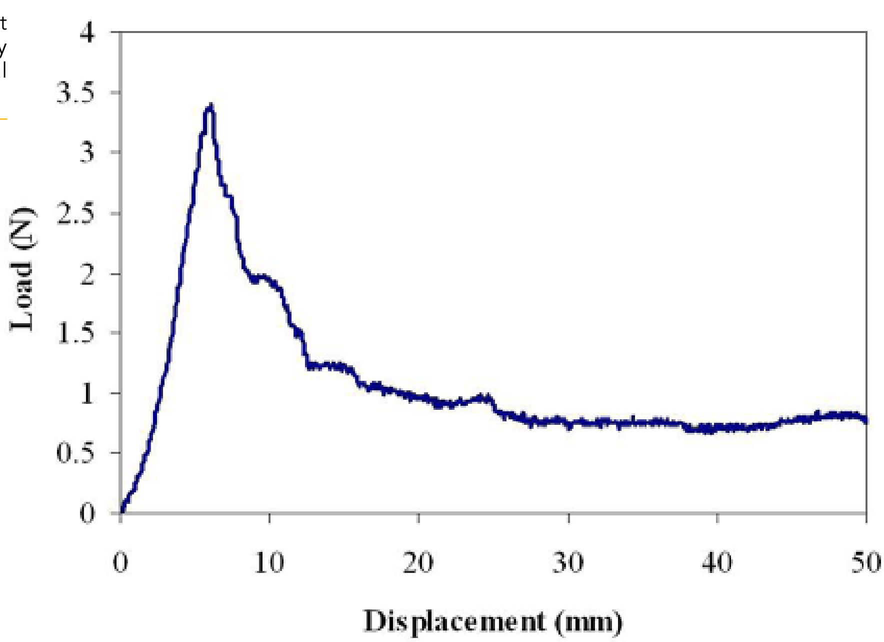

Figure 3. A typical load-displacement plot for a steel/SFRM joint tested using the newly developed laboratory test method. Typical crack velocity was 0.4 mm/s.

Will it Stick?

Adhesion research has focused on the development of new testing methods for both laboratory and field use. A new test method for lab use has been drafted and submitted for consideration to the ASTM E06.21 subcommittee on Serviceability. Entitled "Standard Test Method for Measuring Fracture Energy of Spray-Applied Fire-Resistive Materials Applied to Structural Steel Members," it is based on the simultaneous measurement of load and crack opening during a peel-type test to remove the FRM from the underlying substrate. A movie demonstrating this test method has been produced and is available at http://concrete.nist.gov/FRMexp8.swf. Typical load-displacement results obtained during the testing of a steel/FRM joint are provided in Figure 3.

Concurrently with the development of a laboratory test method, research has focused on the creation of a field test

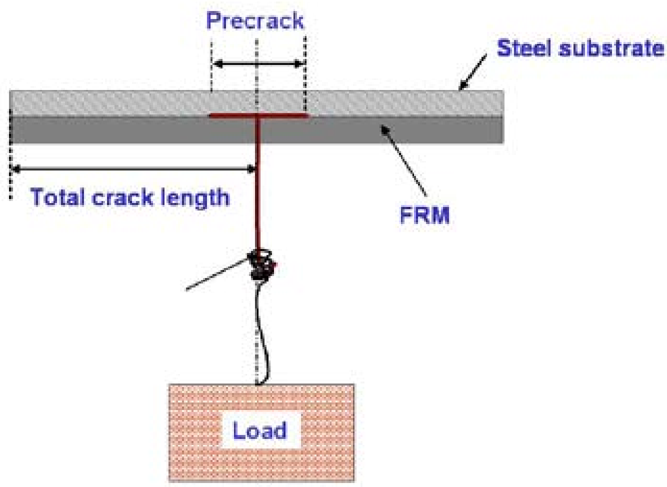

Figure 4. Schematic representation of the proposed field test method for measuring the fracture energy of the FRM/steel system.

method that would also provide a measure of the fracture energy of the FRM-steel system in real-world conditions. A prototype for a field test method to replace the so-called "mayonnaise cap" test (ASTM E736) has been successfully demonstrated. It consists of a cylindrical pin that is attached magnetically to the steel substrate prior to the application of the FRM. After application and curing, at a desired testing age, a simple loading test is conducted to measure the fracture energy of a known tested cylindrical area (see Figure 4).

As with the conventional E736 test method, sample isolation remains an unresolved issue. Possibilities to be explored further including cutting through the FRM to the steel surface using a circular template or placing a square section of release paper with a circular hole between the FRM and the steel at these testing locations prior to the FRM application to facilitate the isolation process. In the near future, the adhesion research will use these new testing protocols to examine the critical adhesion performance of these materials at high temperatures. Preliminary results indicate a substantial decrease in bond strength when these systems are exposed to elevated temperatures in a furnace.

Reports summarizing the research conducted during the course of this project can be conveniently found at **http://concrete.nist.gov/monograph/** under Part II: Fire-Resistive Materials. The development of the new test for assessing thermal conductivity at elevated temperatures also has been featured in the NIST Tech Beat (available at **http://www.nist.gov/public_affairs/techbeat/tb2008_1001.htm#slug**) and highlighted in the Federal Laboratory Consortium (FLC) newsletter (available at **http://www.federallabs.org/news/top-stories/articles/?pt=top-stories/articles/1108-01.jsp**). MSC