Post Impact

The focus on durability of fire-resistive materials in structures

THE POST-IMPACT COLLAPSE of World Trade Center Buildings One, Two, and Seven following the terrorist attacks of September 11, 2001, prompted several studies to determine the factors that contributed to their collapse and to recommend design and construction improvements that might address such disasters in the future. One conclusion of these analyses was the crucial role fireproofing plays in overall building safety.

Rising 52-stories and encompassing 1.7 million-square feet (158,000-square meters), 7WTC represents a milestone in skyscraper construction. The building features innovation in design, life safety, and technology. The tower is scheduled to be complete in late 2005.

By **Philip A. Zanghi**

Photographs by **Steve Dapkiewicz**

7 World Trade Center as seen from street level.

Constructed of steel and concrete with a glass facade, 7WTC will be taller than its predecessor. Designed by architect David Childs of Skidmore, Owings & Merrill LLP, the building will include enhanced safety features such as fireproofing material twice as durable as currently required, reinforced concrete walls protecting the building's core, and wider stairs for quicker evacuation.

According to the New York City building code, all steel buildings must be fireproofed, so fireproofing was one of the main considerations when it came to building safety requirements for the new 7WTC.

Fireproofing typically refers to the protection of the structural steel and other supporting members in a building.

Structural fireproofing for steel can be anything from concrete encasement, to mineral fiber, intumescent coating or lightweight cementitious materials applied to the steel to prevent overheating and determination of key structural members.

Fireproofing materials as part of an assembly are also tested and rated in accordance with NFPA 251, *Methods of Tests of Fire Endurance of Building Construction and Materials*.

Emphasis on fireproofing

In May 2002, the Federal Emergency Management Agency (FEMA) published the ***World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations***, in which fireproofing was cited as one of the critical issues in relation to building performance. According to the report, "Fireproofing needs to adhere under impact and fire conditions that deform steel members, so that the coatings remain on the steel and provide the intended protection." Further, in Appendix A, the report states, "Both the sprayed fiber and, to a lesser extent, cementitious materials, can sometimes fail to adhere to the steel, be mechanically damaged, or otherwise be degraded when exposed to a fire. The current quality control testing of adhesion/cohesion and density, while helpful, does not solve the problem of assuring that the fireproofing will be present at the time of a fire and function throughout the duration of the fire exposure. Other factors that can affect the durability and performance of fireproofing include resistance to abrasion, shock, vibration, and high temperatures."

In addition, the National Institute of Standards and Technology (NIST) conducted a three-year building and fire safety investigation to address these issues and to offer recommendations moving forward. The recommendations, contained in 43 draft reports, were summarized and released in June 2005 for a six-week public comment period. Among the draft recommendations was "Enhanced Fire Resistance of Structures–The procedures and practices used to ensure the fire resistance of structures should be enhanced by improving the technical basis for construction classifications and fire resistance ratings; improving the technical basis for standard fire resistance testing methods; using the 'structural frame'

approach to fire resistance ratings; and developing in-service performance requirements and conformance criteria for spray-applied fire-resistive materials (SFRMs, commonly referred to as 'fireproofing' or 'insulation')."

The recommendations of the draft report will be discussed further when the Technical Conference on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster, is held September 13 to 15 at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland.

Some version of the fireproofing recommendations are expected to be part of the final report. In addition, NIST is trying to put together a research group to look into the durability of fireproofing over the next few years. Underwriters' Laboratories, Inc. (UL) is writing a fireproofing durability standard, as well.

The type of fireproofing specified for the 7WTC project is a medium-density, portland cement-based fireproofing product that was chosen for its ease of installation, adhesion properties, and consistency.

Spray-applied fireproofing is only effective when it remains on the steel structure to which it is applied. The mineral fiber fireproofing used in many office buildings has a bond strength of 150 pounds per foot^2 (68 kilograms per 0.3 meters^2).

Fireproofing classifications are measured in terms of density. Technically, density refers to the amount of mass per unit volume. Michael Patti, president of Patti & Sons, Inc., the fireproofing contractor for the project, says "Typical standard density fireproofing products generally have an in place density of 15 pcf (pounds per cubic foot); however, Grace Construction Products' Monokote Z-106/HY fireproofing provides a minimum density of 22 pcf. Higher density material means increased physical performance." See Table 2 for typical applications of higher density product.

Fireproofing classifications and typical use

NFPA 5000® *Building Construction and Safety Code®*, defines "sprayed fire-resistive material" as a cementitious or fiberous material that is spray-applied to structural elements, walls, floors, and roofs to provide fire-resistive protection.

Cementitious fireproofing materials generally contain binders such as portland cement or gypsum as their main ingredient, which, when mixed with water at the job site, forms a slurry that is suitable for pumping and spraying onto steel. The main ingredient of sprayed mineral fiber fireproofing materials typically contains rock wool fiber, which is manufactured by spinning molten pieces of iron slag at high temperatures. These fibers are then mixed with a cement binder to create a mixture that is pumped pneumatically at the job site.

The gypsum-based cementitious, cement-based cementitious, and sprayed fiber materials can be manufactured such that, when applied according to the manufacturer's instructions, they can achieve a targeted dry density measured in pounds per cubic foot. In the fire protection industry, the terms used for varying levels of protection are "standard density," "medium density," and "high density." Performance characteristics that affect durability such as bond strength and compressive, impact penetration, and abrasion resistance increase as dry density increases. See Table 2 for recommended minimum specified performance characteristics.

Across a single project, the fireproofing may experience different types and levels of exposure, such as vibration due to mechanical equipment, high humidity from an unconditioned space, air current in an elevator shaft, and impact in an unconcealed space, just to name a few. Therefore, a combination of different product types are generally used to address the varying conditions present on most projects. Table 2 also lists where standard-, medium-, and high-density products are typically used.

Manufacturers offer guidance to specifiers on where the need for more durable fireproofing would warrant a medium- or high-density product and help them write clear directions in Division 7 of the CSI specifications.

Installation and inspection requirements

The characteristics and performance properties of spray-applied fireproofing have been extensively tested and studied for over 50 years. Relying on correlations developed between in-place properties and fire test performance, building codes mandate special inspection requirements at the time of installation.

Section 40.5, "Quality Assurance for Sprayed Fire-Resistive Materials," in Chapter 40 of NFPA 5000 details surface conditions, ambient temperature during application, thickness, density, and bond strength requirements for sprayed fire-resistive materials. According to Section 40.5, a quality assurance program is the responsibility of the registered design professional.

A construction worker sprays fireproofing inside 7 WTC.

The program, according to Table 40.5.1.2 of NFPA 5000, must include a review of the quality control of the material, a review of the material to determine its conformity to specifications, and verification that the installation is correctly applied and complies with the manufacturer's instructions.

The special inspections are conducted by inspectors from the jurisdiction or by private inspection firms specializing in this service. Documentation and verification of satisfactory results is required for every job. Due to the tight inspection requirements and significant equipment investment, fireproofing is typically applied by trained specialty contractors.

Unfortunately, thorough fireproofing inspection is only required and performed at the time of installation and does not capture the long-term effects on the fireproofing of external factors such as environmental elements and human behavior. While codes such as NFPA 1, *Uniform Fire Code*™, require such materials to be maintained, there are no inspection protocols for these materials.

To ensure that passive fire protection products remain in place for the expected life of the structure, the products and systems must be inspected regularly throughout the life of the building.

Standard for durability tests

In mid-2003, in response to comments in the 2002 FEMA report, UL assembled a group of industry experts, including members of UL's

TABLE 1. RECOMMENDED USE BY FIREPROOFING DENSITY PER ASTM STANDARDS

Performance Characteristic	Standard Density	Medium Density	High Density
Bond Strength (ASTM E 736)	200 psf	2,000 psf	10,000 psf
Compressive Strength (ASTM E761)	1,200 psf	100 psi	550 psi
Air Erosion (ASTM E859)	0.005 g/ft^2	0.000 g/ft^2	0.000 g/ft^2
Impact Penetration (City of San Francisco)	Max. 6 cm^3 abraded	—	—
Abrasion Resistance (City of San Francisco)	Max. 15 cm^3 abraded	—	—

Fire Council and Standards Technical Panel (STP) 263 on Fire Resistance of Building Construction and Assemblies, to develop UL 2431, *Standard for Durability Tests for Fire Resistive Materials Applied to Structural Steel.*

UL was also contracted by NIST to test the steel-joist-supported floor system of the Word Trade Center towers under the fire conditions prescribed in ASTM E119, which included a specific thickness of fireproofing.

The STP is currently working on it's third draft of UL 2431, which will provide a means of measuring the ability of fire-resistive materials to retain their fire-resistive properties after being subjected to various conditioning environments. The fire-resistive performance will be determined by measuring the temperatures of steel tubes protected by the materials.

The conditioning environments include abrasion; aging; a combination of wet, freeze, and dry cycling; humidity; impact; industrial atmosphere; salt spray; ultraviolet light; and vibration. Two fire exposures are defined, a normal-temperature-rise fire and a-rapid-temperature rise fire. The normal-temperatur-rise fire is intended to represent a fully developed interior building fire. The rapid-temperature-rise fire is intended to represent a hydrocarbon pool fire.

"We have a number of working groups that are in the process of completing their assignments, and I expect the STP to meet during the fourth quarter pursuant to completing the draft standard and advancing the document to initial ballot and public review," says Daniel P. Ryan, Standards Technical Panel Chair at UL.

NFPA has assisted with this project. Bob Berhinig, UL's principal engineer for Fire Resistance was invited to make a presentation on the development of UL 2431 at the NFPA World Safety Conference and Exposition® in Salt Lake City in 2004. Feedback from the presentation was incorporated into the UL 2431 development effort, Ryan says.

When the work is completed, architects and specifiers will have a clearer understanding of which products are compliant with the intended application. Until then, manufacturers should provide sufficient evidence that the products they offer will withstand the anticipated need for long-term durability.

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TABLE 2. TYPICAL USES

Product Type	Nominal Density	Typical Use
Standard-Density	13-17 pcf	• Interior concealed commercial
Medium-Density	22 pcf	• Interior exposed areas • Parking garages • Mechanical rooms • Elevator shafts • Swimming pool areas
High-Density	40 pcf	• Exterior exposure • Industrial facilities • Manufacturing facilities • Transportation terminals