Structural Fire Protection

common questions answered

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AISC engineers and a representative from the NFPA provide answers to questions about the materials, components and systems designed to provide life safety and structural integrity during fires.

What is a fire load? Where do fire loads primarily come from in buildings?

Fire loads account for all combustible building contents, including furnishings, equipment, and combustible construction components. Most of a building's fire load results from contents that have been introduced after the construction is complete. The fire load is usually expressed in terms of the "wood-equivalent" weight of combustible building contents per unit building-floor area in psf. The actual weight of combustible contents is adjusted to the wood-equivalent weight based on the estimated potential heat of contents normalized to the potential heat of wood (8000 Btu/lb). Alternatively, the fire load could be expressed in terms of the potential heat of building contents per unit building-floor area in Btu/ft^2.

How fast does a conventional fire spread?

The rate at which a fire spreads and grows in a building depends on many factors:

- the combustion properties of the construction materials
- building furnishings and contents
- ventilation conditions
- room geometry and configuration
- timely detection and effectiveness of fire suppression response by occupants and/or firefighters
- availability and effectiveness of automatic fire detection and suppression systems
- availability and effectiveness of fire barriers

At what temperature does a typical fire burn?

The duration and the maximum temperature of a fire in a building compartment depend on the amount and configuration of available combustibles, ventilation conditions, properties of the compartment enclosure, and weather conditions. The maximum temperature of a fully developed building fire will rarely exceed 1800°F. The average gas temperature in a fully developed fire is not likely to reach 1500°F. Temperatures of fires that have not developed to post-flashover stage will not exceed 1000°F.

What is "thermal mass"?

Thermal mass is used sometimes for effective specific heat or heat capacity. Effective specific heat in Btu/(lb°F) is the amount of energy, per unit mass of material, required to raise the temperature of the material by one temperature unit. Similarly, effective-heat capacity in Btu/(ft^3°F) is the amount of energy, per unit volume of material, required to raise the temperature of the material by one temperature unit. For most construction materials, specific heat and heat capacity values (as well as thermal conductivity values) are temperature dependent. This means that these values change in the temperature range associated with building fires (50°F to 1800°F), because many materials undergo physicochemical changes at elevated temperatures. These thermal properties are also sensitive to the testing method used, and different sources list varying values of material properties for the same material.

What is a heat sink? Where are they found?

A heat sink refers to anything absorbing large amounts of heat through physical and/or chemical processes. Materials containing large amounts of chemically combined water in their structure, like gypsum or concrete, can form heat sinks. They absorb significant amounts of heat due to the energy consumed in the water-evaporation process. Materials with high thermal conductivity and high effective-heat capacity will also act as heat sinks. Materials with low thermal conductivity will reflect and not absorb heat.

What is flashover?

Flashover is an abrupt transition from the burning of a small number of items in the room, or a small portion of the room, to full-room involvement in a fire. Room-fire flashover is a state in which all the combustible contents of the room experience a nearly simultaneous ignition. Most fires never reach flashover because they are extinguished before this can occur. Some fires self extinguish when the air supply is insufficient, or when the fire has a low-enough energy source to prevent ignition of multiple targets.

The time to flashover depends on many factors, such as the properties of combustibles, the size of the room and ventilation conditions. In larger rooms, the time to flashover will usually be longer. In well-ventilated large premises, like open parking garages and large atriums, flashover is unlikely. Flashover is also unlikely to occur in sprinklered premises.

Where can one find the thermal conductivity or thermal resistance values of different fire-protective materials?

A good source is the third edition (2002) of the *SFPE Handbook of Fire Protection Engineering* by the Society of Fire Protection Engineers (www.sfpe.org). For some materials, information might be unavailable.

What is the meaning of "fire resistant"? Is it the same thing as "fireproof"?

Fire resistance is the ability of building components and systems to perform fire-separating and/or load-bearing functions under fire exposure. Fire-resistant building components and systems are those with specified fire-resistance ratings based on fire-resistance tests. These ratings, expressed in minutes and hours, describe the time duration for which given building components and systems maintain specific functions while exposed to simulated fire events. Various test protocols describe the procedures to evaluate the performance of doors, windows, walls, floors, beams and columns.

The term *fireproof* is a misnomer—nothing is truly fireproof. All construction materials, components and systems have limits and can be irreparably damaged by fire.

Is steel a fire-resistant system or material?

Fire-resistance ratings are assigned to construction components and systems, not materials. Materials are classified for their combustion properties, and steel is non-combustible. Steel also exhibits other valuable structural and durability properties. It is used in many fire-resistant building components and systems, where load-bearing structural-steel members are insulated from the thermal effects of a fire.

What are spray-applied fire-protective materials made of?

Spray-applied fire-protective materials fall into two broad categories: mineral fiber and cementitious. These materials are based on proprietary formulations, supplied in a dry form, and must be mixed and applied according to the manufacturer's recommendations.

The mineral-fiber mixture combines fibers, mineral binders, air and water. It is usually spray-applied. The dry mixture of mineral fibers and binding agents is fed to a spraying nozzle. Water is added to the mixture in the nozzle as it is sprayed onto the metal surface. In its final, cured form, the mineral-fiber coating is lightweight, noncombustible, chemically inert and a poor conductor of heat (a low thermal conductivity insulator).

Cementitious coatings incorporate lightweight aggregates, like perlite or vermiculite, in a heat-absorbing matrix of gypsum and/or Portland cement. Some formulations also use magnesium oxychloride, magnesium oxysulfate, calcium aluminate or ammonium sulfate. Various additives and foaming agents can be added to the mixture. Cementitious coatings are often classified by their density (as low, medium and high).

Other than spray-applied fire-protective materials, what other materials/methods can be used to fire protect steel?

Concrete and masonry encasements are traditional fire-protective materials that can be used. Gypsum-board and mineral-board products, ceramic-wool wraps, and various intumescent coatings are common alternatives. Steel itself is an effective fire-protective material when used in sheet form to provide a protective and reflective shield for other materials. Steel can also be used in the form of meshes or wraps to help other materials maintain their integrity under heat exposure. Other fire-protection methods for structural steel include using rain screens—water sprinklers that protect steel members—or filling tubular structures with concrete or water.

In general, structural fire-protection is achieved through one or more of the following mechanisms:

- Low thermal conductivity
- High effective-heat capacity
- Heat-absorbing physical reactions, like transpiration, evaporation, sublimation and ablation; or heat-absorbing chemical reactions, like endothermic decomposition and pyrolysis
- Intumescence, the formation of a thick foam upon heating
- Radiation or reflection.

How do intumescent painting systems work?

An intumescent coating chars, foams and expands when heated. The compounds of intumescent systems generally can be placed into four categories:

1. inorganic acid or material yielding an acid at temperatures of 212°F to 570°F;
2. polyhydric material rich in carbon;
3. organic amine or amide, as a flowing agent; and
4. halogenated material.

Various binders and additives are mixed in to provide specific physical properties of the total system. The system often is made of several coats with different functions. For example, a topcoat will provide a durable finish surface, while the base coat will provide a strong bond to substrate. Extensive development over the last decade has led to improved formulations that do not use traditional compounds.

Can spray-applied fire-protection be applied to painted or galvanized steel?

In most cases, steel that is to be fire-protected should not be painted or galvanized. When such steel must be painted, additional measures can be taken to ensure adhesion. It is prudent to consult a fire-protection contractor and an authority having jurisdiction (AHJ) during early project stages if you expect your painted or galvanized steel to be fire protected by spray-applied materials.

Spray-applied fire-resistive materials can be applied to primed or painted steel shapes provided they have passed bond tests in accordance with ASTM E736 "Standard Test Method for Cohesion/Adhesion of Sprayed Fire Resistive Materials Applied to Structural Members." These tests should indicate a minimum average bond strength of 80 percent and a minimum individual bond strength of 50 percent, compared to the bond strength of the same fire-resistive material when applied to a clean, unpainted/ungalvanized steel-plate surface. Some AHJs enforce similar requirements for galvanized surfaces. Producers of fire-resistive materials usually maintain a list of "pre-approved" paints that have passed the ASTM E736 tests. They can advise on the applicability of a product to galvanized surfaces. Additional tests are needed if a coated-steel surface is not pre-approved. If bond strength is found unacceptable, a mechanical bond can be obtained by wrapping the structural member with expanded metal lath (min. 1.7 lb/sq. yd).

How reliable are sprinkler systems?

Sprinkler systems have proven to be effective and reliable when properly designed, installed and maintained. Strict regulations in the United States enforce standard practices for sprinkler-system inspection, test and maintenance programs. The effectiveness of sprinkler-system performance is noted in the National Fire Protection Association's (NFPA) annual report: "The NFPA has no record of a fire killing more than two people in a completely sprinklered building where the system was properly operating, except in an explosion or flash fire, or where industrial fire brigade members or employees were killed during fire suppression operations."

Are there any structural systems that should be avoided when designing for an area of a building that contains a large fire load?

Building and fire codes usually restrict excessive fire loads or impose restrictions on the height and area of buildings with large fire loads. These restrictions are severe for buildings of combustible construction. Combustible construction is not always permitted for high-hazard occupancies. Even buildings that are deemed to have a minimal fire load, such as office buildings, are subject to codes that limit allowable-construction types and increase fire-resistance-rating requirements as building height and area increases.

What are the general rules-of-thumb for interpreting model building codes when it comes to fire ratings in mixed-use buildings?

Building codes have special requirements for buildings with more than one occupancy group. If different occupancies are separated by firewalls, fire-barrier walls and/or floors, each portion is considered a separate building when establishing allowable heights, areas and fire-resistance requirements (some conditions/exemptions apply).

Without this degree of fire separation, a building of mixed occupancy is limited by the most restrictive height and area requirements specified for any of the occupancies in the building (there are several exemptions). When establishing the fire-resistance requirements for non-separated uses, the regulations applicable to mixed occupancies govern the respective portions of the buildings. Where the requirements conflict, those that provide greater safety prevail.

When a building or system is said to have a two-hour fire rating, what does that mean?

It means that the system has satisfied the requirements for a two-hour rating specified in a relevant standard test. In the case of a building, it could mean that some of the construction elements and/or assemblies in that building have achieved a two-hour rating in a standard ASTM E119 fire-resistance test.

Does a two-hour fire rating mean that a building will last for two hours in a fire?

No. The ratings only reflect the ability of individual components and assemblies in a building to meet the required performance in the standard test. Buildings are classified by types of construction. Each has specific requirements pertaining to the combustibility of construction materials and the fire-resistance ratings required for building components (members, elements) and assemblies (systems). In some fire events, performance exceeds two hours. In a severe-challenge fire, usually the result of an extreme, unanticipated event, performance can be less than two hours.

What is the difference between restrained and unrestrained ratings?

Restrained and unrestrained classifications pertain to ASTM E119 tests on beams, floors and roofs. They depend on whether the test arrangements allowed for free thermal expansion of the tested specimen (unrestrained test) or not (restrained test).

ASTM E119 tests on unloaded structural steel and composite steel/concrete beams can be restrained or unrestrained, but always require the longitudinal expansion of the applied fire-protection material to be restrained (this conservative requirement can result in earlier fall-off of the fire protection and faster heating of the tested steel beam). This test results in a single Unrestrained Beam Rating, based on the period of fire exposure where the average measured temperature at any section of the beam remains under 1000°F, and the measured temperature at any single location of the beam remains under 1200°F. This type of test is conducted only when the loading device has lower capacity than the required test load.

ASTM E119 tests on loaded structural steel and composite steel/concrete beams are always restrained and result in two ratings:

- the Restrained Beam Rating, based on the period of fire exposure where the beam sustains the applied design load, but NOT more than twice the corresponding Unrestrained Beam Rating, AND provided the latter is one hour or more; and
- the Unrestrained Beam Rating, based on the period of fire exposure where the average measured temperature at any section of the steel beam remains under 1100°F, and the measured temperature at any single location of the steel beam remains under 1300°F.

ASTM E119 tests on floor and roof assemblies are always loaded. The assemblies can be tested in the unrestrained or restrained condition around the floor/roof perimeter. Whenever the tested floor/roof assembly contains a structural-steel beam, both restrained

SPRAY-APPLIED FIRE-RESISTIVE MATERIALS, COMMONLY USED TO PROTECT STRUCTURAL STEEL, ARE TESTED FOR:

- ASTM E 84 "Standard Test Method for Surface Burning Characteristics of Building Materials"
- ASTM E 605 "Standard Test Methods for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members"
- ASTM E 736 "Standard Test Method for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members"
- ASTM E 759 "Standard Test Method for Effect of Deflection on Sprayed Fire-Resistive Material Applied to Structural Members"
- ASTM E 760 "Standard Test Method for Effect of Impact on Bonding of Sprayed Fire-Resistive Material Applied to Structural Members"
- ASTM E 761 "Standard Test Method for Compressive Strength of Sprayed Fire-Resistive Material Applied to Structural Members"
- ASTM E 859 "Standard Test Method for Air Erosion of Sprayed Fire-Resistive Materials Applied to Structural Members"
- ASTM E 937 "Standard Test Method for Corrosion of Steel by Sprayed Fire-Resistive Material Applied to Structural Members"

and unrestrained assembly tests will result in an Unrestrained Beam Rating (based on the same temperature criteria specified for loaded restrained beam tests) in addition to Assembly Ratings. For any Assembly Rating period, the unexposed surface of the tested floor/roof should neither develop conditions that will ignite cotton waste, nor exhibit an average temperature rise in excess of 250°F. An unrestrained assembly test will result in an Unrestrained Assembly Rating, based on the period of fire exposure where the assembly sustains the applied design load. A restrained assembly test will result in two assembly ratings:

- the Restrained Assembly Rating, based on the period of fire exposure where the assembly sustains the applied design load, but NOT more than twice the corresponding Unrestrained Assembly Rating, AND provided the latter is one hour or more; and
- the Unrestrained Assembly Rating, based on the same temperature criteria specified for Unrestrained Beam Rating. This excludes steel structural members spaced 4' or less on center, where the criterion for the average measured temperature of all members remaining under 1100°F applies.

Are structural steel systems restrained or unrestrained?

Appendix X3 and Table X3.1 of ASTM E119 provide guidance on the classification of beams, floor and roof systems as restrained or unrestrained. Structural-steel beams and floor systems within steel-framed buildings are classified as restrained.

How can one determine a fire rating for a system that has not been prequalified, such as a concrete-encased steel column?

Concrete-encased steel columns have been "pre-qualified" by many fire tests. These columns are of generic design and are not listed in the Underwriters Laboratories (UL) directory. However, most building codes, such as IBC (Table 719.1(1) and Article 720.5.1.4), and ASCE/SFPE 29-99 (Article 5.2.4), contain specifications to determine the fire resistance of concrete-encased columns. These specifications are based on extensive experimental data from standard (ASTM E119) fire-resistance tests.

Concrete-filled HSS columns are another example of generic construction that is not listed in the UL directory. Article 5.2.3 of ASCE/SFPE 29-99 specifies how to determine the fire resistance of concrete-filled hollow steel columns. The relevant background information can be found in:

V. K. R. Kodur, and D. H. MacKinnon, "Design of Concrete-Filled Hollow Structural Steel Columns for Fire Endurance", *Engineering Journal*, First Quarter, 2000, pp. 13-24.

Does the grade of steel used affect its response to a fire?

Common structural-steel grades exhibit similar deterioration of mechanical properties at elevated temperatures, and all structural grades perform essentially the same way. There have been efforts in several countries to introduce a "fire-resistant" steel grade into construction. This steel reportedly exhibits improved properties at elevated temperatures. However, its use remains limited in construction because improved mechanical properties of steel at elevated temperatures do not translate into significant increases in the fire resistance of building elements and systems.

How does a fire impact steel connections? Does it affect connections differently than the members themselves?

Connections usually contain more material (additional plates, bolts, etc.) than connected members. Often connections also have less exposure to heat and a higher capacity for heat dissipation because of their proximity to other members. As a result, temperatures are likely to rise faster in members than in connections, making connections less critical for fire-protection design.

Can steel continue to be used in a building after it has been in a fire? How can you assess the capacity of steel that has been exposed to fire? Are there concerns about internal or residual stress effects that have to be considered?

Steel is born in a melting process that is significantly hotter than any building fire, and significant residual stresses are present in all newly manufactured steel members. A detailed discussion of post-fire steel assessment issues is provided in:

R. H. R. Tide, "Integrity of Structural Steel After Exposure to Fire", *Engineering Journal*, First Quarter, 1998, pp. 26-38.

A general rule of thumb: "If it is still straight after exposure to fire—the steel is okay." Straightening techniques are available for steel members that have been misaligned after fire exposure.

What percentage of its total capacity does a steel beam retain when subjected to the heat of a normal fire? At what temperature does steel lose all of its capacity?

The strength of steel remains essentially unchanged until about 600°F. Steel retains about half of its strength at 1100°F, and loses all of its capacity when it melts at about 2700°F. For design purposes, it is usually assumed that all capacity is lost at about 2200°F.

How do concrete- or water-filled tubular steel columns perform in a fire?

Water or concrete inside tubular-steel members act as heat sinks. They reduce temperature rise in the steel and significantly enhance fire resistance. In the case of concrete-filled tubular columns, the concrete also contributes to the load-bearing capacity when the outside steel shell deteriorates under heat exposure.

Compared to regular steel framing, how do steel joists, channels, tees or castellated beams perform in a fire? Are there any special procedures required to fire protect them effectively?

Open-web steel joists and castellated beams are proprietary system designs. For many of them, fire-resistance ratings are listed in the UL and other fire-resistance directories.

Which document specifies the fire-resistance requirements for the structural system?

The building code of the jurisdiction, which is usually based upon the IBC or NFPA model building code, will specify the requirements.

Which ASTM Specifications relate to fire-protection and engineering?

The most relevant ASTM specifications pertain to combustibility, ignition and flammability characteristics, heat- and smoke-release parameters, and fire resistance.

ASTM E119 specifies standard test procedures to establish the fire-resistance (endurance) ratings for construction elements (beams, columns) and assemblies (walls, floors, roofs). There are several other ASTM tests that establish fire-resistance ratings for windows, doors, fire-stops, and other components. Many ASTM specifications ensure the quality performance of relevant products (See table).

I have heard that the ASTM fire specifications are undergoing revision. Is this because of the World Trade Center attacks?

ASTM specifications are revised routinely every few years. Like many codes and standards, revisions are promulgated on a periodic basis to recognize new technologies and methods as well as new materials.

I have heard that the 2005 AISC *Specification* is going to address fire protection and engineering. What kinds of issues is the Specification going to address?

The *Specification* will provide a general outline of procedures for engineered structural fire-protection design that will include steel properties at elevated temperatures, expected fire exposures, heat-transfer calculations, load combinations for fire-limit states, and analysis of heated structures.

What is performance-based design with respect to fire?

Performance-based design consists in part of well-defined performance goals, objectives and criteria for an expected fire event. Thereafter, a corresponding set of systems is designed to achieve these performance objectives and criteria. In many cases, performance-based designs include evaluations of candidate designs against a series of fire-design scenarios.

How prevalent have performance-based designs become in fire protection?

It is still a design option that is typically reserved for use on certain high-profile projects. At this point, it is best described as a design alternative rather than a prevalent design methodology.

What is AISC doing to help people design effectively for fire resistance?

AISC is currently developing a single-source design guide, for engineers and architects, on the fire resistance of structural steel. AISC is researching ways to make engineered fire protection for steel structures more accessible as an alternative to current prescriptive solutions.

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WHERE CAN YOU FIND FIRE RATINGS?

Methods to determine fire-resistance ratings for generic designs can be found in most building codes.

- Chapter 7, "Fire-Resistance-Rated Construction", *International Building Code*, International Code Council, Falls Church, VA, 2000.
- Chapter 8, "Fire Resistive Materials and Construction", *NFPA 5000: Building Construction and Safety Code*, NFPA, Quincy, MA, 2002.
- ASCE/SFPE 29-99, *Standard Calculation Methods for Structural Fire Protection*, Structural Engineering Institute of the American Society of Civil Engineers, Reston, VA, 1998.

Fire resistance ratings for proprietary designs are found in directories published by testing laboratories.

- *Fire Resistance Directory*, Volume I, Underwriters Laboratories Inc., Northbrook, IL, 2002 (updated annually), online directory at www.ul.com.
- *Directory of Listed Products*, Intertek Testing Services NA Inc., Cortland, NY, 2000, online directory at www.etlsemko.com.
- *Directory of Listed Building Products, Materials and Assemblies*, Volume II, Omega Point Laboratories Inc., Elmendorf, TX, 2002 (updated annually), online directory at www.opl.com.