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# Fire Resistance Determination and Performance Prediction Research Needs Workshop: Proceedings

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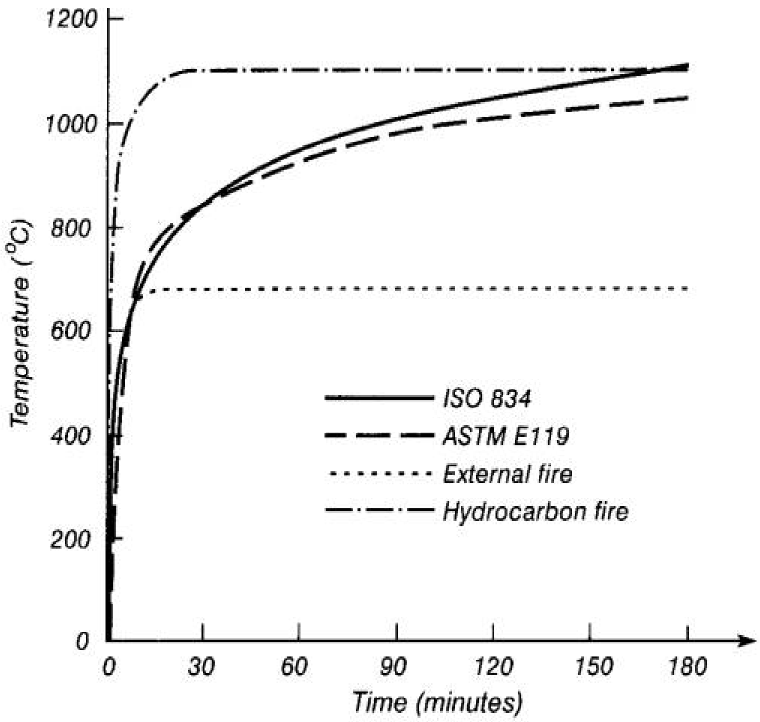


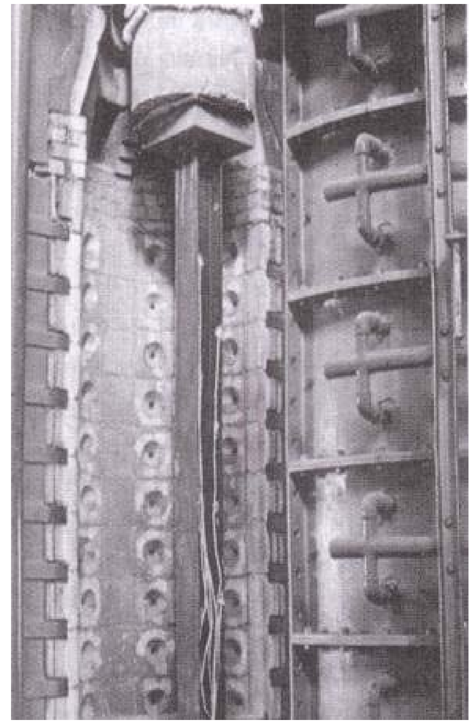

Figure 8. Alternative temperature-time curves for fire resistance tests (left), and a photograph of a steel column ready for testing in the furnace.

## FIRE RESISTANT MATERIALS

### R.B. Williamson

Williamson (Appendix III. K) briefed the participants on the history of fire protection of structural steel and the materials used for that purpose. Dating back to the 1898 Home Life Fire in New York City, a new approach to high rise safety began emerging that required buildings to be constructed of columns, floors, walls and other elements that were fire resistive, defined as the ability of an element to withstand the effects of fire for a specified period of time without loss of its fire separating or load bearing function. This ability was determined by exposure in a furnace to sustained high temperatures. Various temperature-time curves are used today, depending upon the country and application. Figure 8 compares the ISO 834 test, the hydrocarbon fire (ASTM E1529), and external fire exposures to the standard ASTM E119 curve (also shown in Figure 1). A column instrumented for a test is shown on the right.

The first materials used for fire proofing in the early 20th century were traditional construction materials such as masonry or concrete, which led to substantial labor costs and excessive weights. Gypsum-based systems such as wire lath and plaster systems came on the market there-after, but these also suffered labor and weight penalties. Like concrete, these systems derived

Figure 9. Construction worker applying spray resistive material

much of their effectiveness from water of crystallization, which is immune from normal evaporation. Sprayed fire resistive materials (SFRM) were introduced about 40 years ago as a lower labor cost, lighter weight alternative to concrete and lath/plaster. The SFRM also derived its fire resistive properties from water of hydration contained in the gypsum or portland cement used to bind various fibers and other fillers. A worker is shown applying SFRM at a recent construction site in Figure 9.

Williamson [13] specified four performance requirements of SFRM: performance under actual fire conditions; durability and integrity under normal life of structure; durability and integrity under the construction process; and integrity under extreme conditions (earthquakes, thermo-nuclear attack, severe fire). A number of ASTM tests currently are used (in addition to E119 for fire resistance) to address these requirements:

ASTM E605 [14], Thickness and Density
ASTM E736 [6], Test for Cohesive/Adhesive Properties of SFRM
ASTM E759 [15], Effect of Deflection
ASTM E760 [16], Effect of Impact on Bonding
ASTM E761 [17], Compressive Strength
ASTM E937 [18], Corrosion of Steel by SFRM

A fundamental weakness of all of these tests is that they are not well linked to materials science. According to Williamson (Appendix III. K), there are many different SFRM materials commercially available today, but the current test methods do not adequately address the most important properties or the range of conditions from ordinary fires to the extremes of a terrorist attack.

The current method for testing the cohesive/adhesive properties of SFRM (ASTM E736) consists of a disk with a hook for hanging a weight that is attached to the sprayed on fire resistive material with a quick setting adhesive. The material must withstand a minimum weight before becoming dislodged. The weakness of this method is that while failure from poor adhesion can be distinguished from failure due to poor cohesion, the method is incapable of providing failure loads for each, just whichever fails first. Williams [19] suggests an alternative approach to evaluate the adhesive properties separately, using what is called a blister test. Williamson (Appendix III. K) suggests adapting this technique to SFRM. A thin plastic bag with a bladder feed hose can be attached to the rigid steel substrate before applying the fire resistant material. The feed hose would extend beyond the fire resistive material layer. A measured pressure could be applied to the feed hose to cause the bag to inflate, and a blister would grow at the interface of the steel and SFRM to a size related to the interfacial properties.

Williamson concluded his remarks by recommending that the fire and non-fire performance of fire resistive materials be reevaluated in terms of current challenges to buildings and other structures. A new approach to testing and approvals is necessary, supported by sound research to characterize the available materials and to establish the micro-structure/property relationships that are central to materials science.

**<u>F. Mowrer</u>**

Mowrer (Appendix III. J) listed a series of steps that typically might occur when a building is fireproofed.


Figure 10. Missing spray-on fire proofing around a connection (left ) and missing fireproofing panels on a steel column (Mowrer).

These include the following:

- structure erected
- fireproofing applied
- fireproofing inspected (maybe)
- fireproofing scraped off
- other building services installed
- everything covered with finishes
- fireproofing forgotten

Conditions that are troublesome include connections, attachments, members with extreme W/D ratios, long spans, and end restraints. Since connections are not evaluated in tests, what is the best way to protect them against fire? How much fireproofing do attachments require, and is it a function of the thickness and/or length of the element? Fireproofing thickness requirements are based upon standard geometries; how do those relate to round members and other non-planar arrangements? Four meters is about the maximum span tested; how are the fireproofing requirements extrapolated to spans that are considerably longer? Furnace test articles are often wedged into the frame; how does this arrangement relate to real-world constraint conditions? How can deficiencies in fire proofing be identified during inspections, and how can they be corrected? If fire proofing is damaged or missing, how does that impact the overall performance of the structure? (See Figure 10.) These are all issues that require research solutions.

**R. Iding**

Iding (Appendix III. L) presented several case studies of performance-based structural analysis to determine fireproofing requirements [20]. There are three key elements in the approach:

- Fire Hazard Analysis - identify all possible fire scenarios and determine gas temperatures achieved adjacent to structural members.
- Thermal and Structural Analysis - calculate temperature history in structural elements and the elements' response (forces and stresses) to the fire with varying levels of fireproofing.
- Risk Mitigation Plan - revise fireproofing scheme, or devise alternative risk reduction schemes, to ensure performance is acceptable for type of building being designed.

A step-by-step methodology was described, with examples given for a transient trash fire in a power plant and fireproofing for an unusual structure for which no prescriptive code applied: the Eiffel Tower II in Las Vegas.

The following specific recommendations were provided by Iding:

- identify material properties at elevated temperatures, particularly those of spray-on fire proofing and intumescent paint
- develop analytical tools for structural connections
- develop peer review protocol for performance-based analysis during transition to new methodology
- incorporate basic capabilities for fire analysis into commercial computer codes that can handle non-linear structural effects

- expose engineering students and practitioners to basics of structural fire analysis and computational tools, and sponsor workshops for non-specialists
- codify methods to calculate fire curves for most common scenarios to assist design engineers for routine applications
- examine fire safety of building as a whole and develop practical methods to avoid progressive collapse that could be incorporated into performance-based building codes

**A. Astaneh**

Astaneh (Appendix III. M) discussed the protection of steel structures against impact, explosion and ensuing fire. An impact is a force applied on a building over a short time interval, and depending upon the geometry and velocity of the impacting object or pressure wave, dynamic forces are generated throughout the building which can cause serious damage at the local and global level to the structure and fire protection systems. The main route to life safety is by preventing collapse of the building directly following the initial impact and after any ensuing fire. The use of catenary action provided by a floor was presented as a possible technology to mitigate collapse. Cables imbedded in a floor specimen were shown to be able to significantly retard the onset of failure. The gross physical behavior was mimicked in a finite element analysis.

The challenge posed by Astaneh was for realistic modeling of the behavior of steel and composite structures exposed to sustained fires. Data are needed on the fire resistance of light weight and high strength concrete and on steel connections. More realistic models of local and overall buckling of steel and composite structures (including composite shear walls) at elevated temperatures are needed. Composite shear walls with a gap between the wall and frame could be used, for example, to protect egress routes. Research is also needed to better predict the performance of various structural systems, especially at elevated temperatures.

## STRUCTURAL PERFORMANCE

**J-M. Franssen**

The frontiers of structural fire modeling were explored by Franssen (Appendix III. N). The temperature in the structure and mechanical behavior are simulated with SAFIR [21], a non-linear, transient finite element model that determines the structure temperature as a function of three directions and the gas temperature, and determines the 3-dimensional displacements as a function of the structural temperature and loads. Limitations on computational resources constrain the capabilities of the mechanical model when 3-dimensional temperature field calculations such as those in Figure 11 are made. Beam finite element calculations provide a link between the thermal and mechanical analysis of the structural frame. Shell finite element calculations work well on thin elements and can successfully predict severe deformations, as shown in Figure 12.

The limits of structural fire modeling are associated with eight factors. (1) The first factor is the lack of thermal properties of structural materials (the thermal conductivity of concrete, for example, is presently under discussion in Europe, as well as the impact of radiative heat transfer to H-steel sections, the so called shadow effect that reduces the radiation to the inner surface of a