Fire Resistive Coatings

The Need for Standards

Lieff/Stumpf
editors

ASTM STP 826

FIRE RESISTIVE COATINGS: THE NEED FOR STANDARDS

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ASTM Committee E-6 on Performance
of Building Constructions
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Morris Lieff, County College of Morris, and
F. M. Stumpf, United States Mineral
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Foreword

The symposium on Fire Resistive Coatings: The Need for Standards was presented at Philadelphia, Pa., 18 Oct. 1982. The symposium was sponsored by ASTM Committee E-6 on Performance of Building Constructions. Morris Lieff, County College of Morris, and F. M. Stumpf, United States Mineral Products, presided as cochairmen and coeditors of the publication.

Related ASTM Publications

Performance of Organic Coatings, STP 781 (1982), 04-764000-48

Fire Risk Assessment, STP 762 (1982), 04-762000-31

Building Codes—Compilation of ASTM Standards in Building Codes, 20th Edition (1982), 03-002082-10

ASTM Fire Test Standards (1982), 03-505082-31

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

ASTM Editorial Staff

Contents

Introduction

The impetus for organizing this symposium has come from two stimuli. First, Subcommittee E06.21 on Serviceability Performance of Building Constructions has been working on the development of test methods for sprayed fire-resistive materials applied to structural members since 1964. At the present time the following seven test methods have become ASTM standards:

- Tests for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members (E 605–77)
- Tests for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 736–80)
- Test for Effect of Deflection on Sprayed Fire-Resistive Material Applied to Structural Members (E 759–80)
- Test for Effect of Impact on Bonding of Sprayed Fire-Resistive Material Applied to Structural Members (E 760–80)
- Test for Compressive Strength of Sprayed Fire-Resistive Material Applied to Structural Members (E 761–80)
- Test for Air Erosion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 859–82)
- Test for Corrosion of Steel by Sprayed Fire-Resistive Material Applied to Structural Members (E 937–83)

ASTM Task Group E06.21.08 is presently developing a standard practice for application and inspection of sprayed fire-resistive materials. Several papers presented in this symposium represent preparatory studies for this task group work.

A second stimulus has been the participation of one of the cochairmen of this symposium in the Joint Working Group 10.03, Building Materials and Components Project 10.03.01.06, "Fire Resistance of Buildings and Structures," which was part of the United States-Union of Soviet Socialist Republics (US-USSR) Agreement on Cooperation in the Field of Housing and Other Construction.

In 1978, the American cochairman of the US-USSR working group extended an invitation to this editor to join the group as an American expert on fire resistive coatings. As part of the exchange protocol, a survey paper was prepared on Fire Resistant Coverings in the United States, which was forwarded to the U.S.S.R. In July 1981, this editor visited the U.S.S.R. as part of a six-member U.S. delegation.

It became very obvious during this work that there was a scarcity of available technical information concerning any aspects of sprayed fire-resistive materials in our literature. This realization crystallized in our minds the need for the organization of this symposium.

This volume should be of use to all who need to be aware of recent research on fire resistive coatings. It should be of particular interest to architects and engineers who specify their use of fire resistive coatings to the contractors who install them, and to the building owner, the manufacturers, and scientific and technical research and development personnel.

We hope that the papers presented at this symposium are only the beginning of a steady flow of information, and that this symposium will stimulate and encourage further research, development, and publication of information that is so much needed as a resource for the development of more and better standards.

As cochairmen of the symposium, we wish to thank the authors, the participants and the staff of ASTM, specifically Kathy Greene, Theresa Smoot, and Susan Gebremedhin. Without their joint efforts, the symposium could not have taken place and this STP could not have been published.

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Morris Lieff[1]

Fire Resistant Coverings

REFERENCE: Lieff, M., "**Fire Resistant Coverings,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 3–13.

ABSTRACT: Thin coatings (fire retardant) are used to reduce combustibility or surface flame spread of wood or cellulosic building materials. Thick coatings are used to provide fire resistive protection of steel. The characteristics of intumescent and nonintumescent coatings, and thick insulative and energy absorbing (ablative) materials are discussed. Methods of testing are reviewed.

KEY WORDS: fire resistance, fire retardant coverings, fire resistive coverings, intumescent, insulative, ablative, test method, fire resistive coatings

Fire resistance in accordance with ASTM Terminology Relating to Fire Standards (E 176-82a) is defined as the property of a material or assembly to withstand fire or give protection from it. As applied to elements of buildings, it is characterized by the ability to confine a fire or to continue to perform a given structural function or both. Fire retardant according to ASTM E 176-82a is defined as having or providing comparatively low flammability or flame spread properties.

The thickness of covering used to provide protection for building in fire environments is dependent on the need and is basically determined by the substrate. Thin coatings, which are generally called fire retardant, are applied over wood or cellulosic building materials to reduce combustibility or surface flame spread. Thick coatings are used primarily to provide fire resistive protection of steel. In order to develop fire resistive ratings, the absorption of heat by the structural steel must be minimized. This is achieved by thickness ranging from 3 to 50 mm (⅛ to 2 in.) or more. Intumescent mastic coatings are at the lower thickness range of 3 to 6 mm (⅛ to ¼ in.) whereas cementitious and fibrous coverings range from 9.5 to 50 mm (⅜ to 2 in.) or more.

Note: Unpublished report prepared as part of the United States-Union of Soviet Socialist Republics (US-USSR) agreement on Cooperation in the Field of Housing and Other Construction Joint Working Group 10.03, "Building Materials and Components," Project 10.03.01.06, "Fire Resistance of Buildings and Structures." The terms "covering" and "coating" as used in this paper are synonymous. The title, *Fire Resistant Coverings,* appears in the protocol of the joint working group. However, coating is more commonly accepted and used in the United States.

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Fire Retardant Coverings

Fire retardant coverings (paints) that help shield underlying surfaces from damage by fire have shown a growing use in recent years. They are designed for life safety rather than building protection. They are used, for example, to protect the walls and ceilings of hospitals, nursing homes, schools, and ships. They can provide 10 to 20 min of additional time in which to evacuate safely the occupants from within the building. Their greatest use is in areas such as stairwells, corridors, or where safe egress is necessary. Such locations in the buildings require that the flame spread of the materials used be very low.

Fire retardant paints serve to delay ignition and to reduce the flame spread of a combustible surface. They provide a protective layer that accomplishes these objectives in one or more of the following ways:

(1) provides a noncombustible layer over the flammable surface,
(2) liberates inhibiting gases,
(3) absorbs heat on decomposition,
(4) liberates water when heated, maintaining the substrate temperature at 100°C for an extended period of time,
(5) on heating accelerates the formation of char, and
(6) swells in heating (intumesces) thus providing an insulating layer over the surface.

Most fire retardant paints rely on a combination of several of these actions for their effectiveness.

Fire retardant paints may be usefully divided into two broad categories.

(1) intumescent and
(2) inert (do not intumesce).

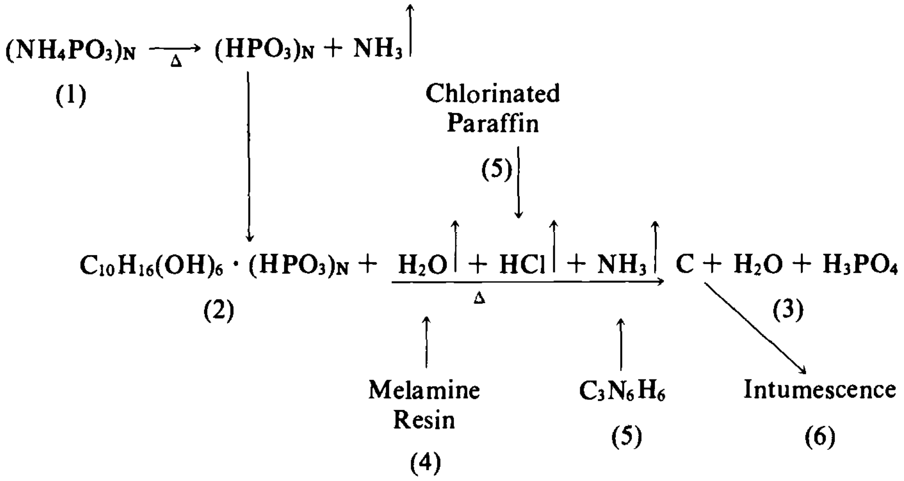
Intumescent

Paints which intumesce are generally more effective than nonintumescent paints. These coatings, when heated, expand by foaming to produce a cellular carbonaceous material that insulates the substrate from heat. Four types of compounds interact to form this insulating layer:

(1) a polyhydric compound to act as a carbon source (carbonific),
(2) a dehydrating agent that is the intumescent catalyst,
(3) a blowing agent, and
(4) a resin binder.

Exposure of the intumescent coating to a high enough temperature causes the compound providing the carbon to react with the dehydrating agent to form a char. Simultaneously, the release of copious quantities of nonflammable gases by the blowing agent causes the char to expand greatly. The resin binder forms a thin layer over the foam and inhibits the escape of the gas. The resulting, greatly expanded coating, often more than 100 times as thick as the original coating, retards the spread of flames by preventing their contact with the combustible substrate.

Carbonifics generally used as a carbon source are a mono, di, or tri pentaerythritol or starch. The most commonly used catalyst is monoammonium phosphate or water insoluble ammonium polyphosphate. The phosphoric acid formed by heating the phosphate reacts with the carbonific to accelerate the char formation. Melamine, which releases ammonia when heated, or chlorinated paraffins, which release hydrogen chloride, serve as blowing agents. An emulsion vinyl copolymer that melts or softens at the appropriate temperature is a common resin binder. Melamine-formaldehyde and epoxy resins may be also used. Figure 1 illustrates the formation of intumescence via ammonium polyphosphate catalysis [1].



1. Catalyst decomposes to phosphoric acid and ammonia.
2. Acid reacts with carbonific.
3. Carbonific decomposes to carbon and regenerates acid.
4. Resin melts to form a film over the carbon.
5. Blowing agents release gases which cause the carbon to foam.

FIG. 1—*The formation of intumescence via ammonium polyphosphate catalysis.*

Nonintumescent

Fire retardant paints are thin coatings that provide flame retardancy from the presence in the retardant coating of one or more of the key elements, such as phosphorus, nitrogen, chlorine, or a volatile compound such as water.

They are based primarily on:

(1) chlorinated alkyds,
(2) alumina trihydrate, or
(3) a combination of chlorinated paraffins and antimony trioxide.

Phosphorus is believed to act as a flame retardant because of its ability to increase markedly the conversion of organic matter to elemental carbon (char) during burning and thus to decrease greatly the formation of flammable gases, such as hydrocarbons. Combustion is also inhibited because the char does not burn readily and interferes with the access of oxygen and heat to the underlying surface thus helping to protect the substrate.

The role of nitrogen is not well understood. It is believed by some that nitrogen is useful only in the presence of phosphorus as in such compounds as diammonium phosphate.

Chlorine and bromine are believed to act in the gas phase. These halogens remove from the flaming gas the hydrogen free radicals that, along with both oxygen free radicals and hydroxyl free radicals, are essential to sustaining the combustion process [*2*]. Burning causes the flame retardant to release either gaseous hydrogen chloride or hydrogen bromide. The hydrogen chloride then apparently reacts with the hydrogen free radicals to form molecular hydrogen gas and chlorine free radicals. Hydrogen free radicals and chlorine free radicals in the presence of a third body combine to regenerate hydrogen chloride. Both of these reactions remove hydrogen free radicals from the flaming gas and thus suppress the burning process.

$$\mathrm{HCl} + \mathrm{H}\cdot \rightarrow \mathrm{H_2} + \mathrm{Cl}\cdot$$

$$\mathrm{H}\cdot + \mathrm{Br}\cdot + \mathrm{M} \rightarrow \mathrm{HBr} + \mathrm{M}$$

Similarly hydrogen chloride may react with hydroxyl free radicals to form water and chlorine free radicals, thus reducing the hydroxyl free radical concentration

$$\mathrm{HCl} + \mathrm{OH}\cdot \rightarrow \mathrm{H_2O} + \mathrm{Cl}\cdot$$

Hydroxyl free radicals are important to the burning process because they react with carbon monoxide to form carbon dioxide and hydrogen free radicals.

$$\mathrm{OH}\cdot + \mathrm{CO} \rightarrow \mathrm{CO_2} + \mathrm{H}\cdot$$

This reaction, being exothermic, plays a significant role in sustaining the combustion.

Antimony trioxide ($\mathrm{Sb_2O_3}$) by itself is ineffective. However, it is very effective when used with a halogenated flame retardant, which upon heating, releases either hydrogen chloride or hydrogen bromide. Released hydrogen chloride reacts with solid antimony trioxide to form antimony chloride ($SbCl_3$) and antimony oxychloride ($SbOCl_3$), both of which are gases. Transported to the flame, these gases interfere with combustion and can cause the flame to be extinguished by reacting with both hydrogen and hydroxyl free radicals.

Alumina Trihydrate suppresses burning by absorption of heat because of decomposition at 220 to 230°C into anhydrous alumina and water vapor, which dilutes and cools the combustible gases.

Testing of Fire Retardant Coatings

The standard method for evaluating the effectiveness of a fire retardant paint is ASTM Standard Test for Surface Burning Characteristics of Building Materials (E 84-81a).

This test method measures the "flame spread" (defined by ASTM E 176-82a as flaming combustion along a surface), that is, the value of relative flammability developed in the 7.5-m (25-ft) long horizontal testing tunnel. The tunnel is essentially a long horizontal flue in which the specimens form the ceiling of this tunnel furnace. An igniting flame located at the end of the tunnel causes ignition of any combustibles present. The test panel is subjected to the flame for 10 min during which time the flame front is observed. The maximum flame progress, the temperature of the exit gases, and the density of the smoke generated are recorded.

The tunnel is standardized by using nominal 25.4-mm (1-in. red-oak wood flooring with an arbitrarily assigned flame spread rating of 100, and with asbestos-cement board, 6.35 mm (¼ in.) thick, on the other end of the scale with a rating of zero. Fuel contribution and smoke developed by the test material are calculated from the increase in smoke and exit gas temperature achieved when burning the specimen. Numerical classifications are thus established for flame spread, fuel contributed, and smoke, which permits the performance of the material to be compared with asbestos-cement and red-oak flooring.

In the United States there are many fire retardant coatings on the market, their formulae being of a proprietary nature. They are used primarily where they are required by building codes and government regulatory agencies. To meet these regulations, the fire retardant coatings must be tested by a recognized laboratory, such as Underwriters Laboratories Inc. (ULI) or Factory Mutual Research which publish the test results [*3,4*]. To qualify for a listing as a fire retardant coating, the paint must reduce the flame spread of Douglas fir at least 50%.

The values of the flame spread, fuel contributed, and smoked developed are published for many commercially available products whose formulae are of a proprietary nature.

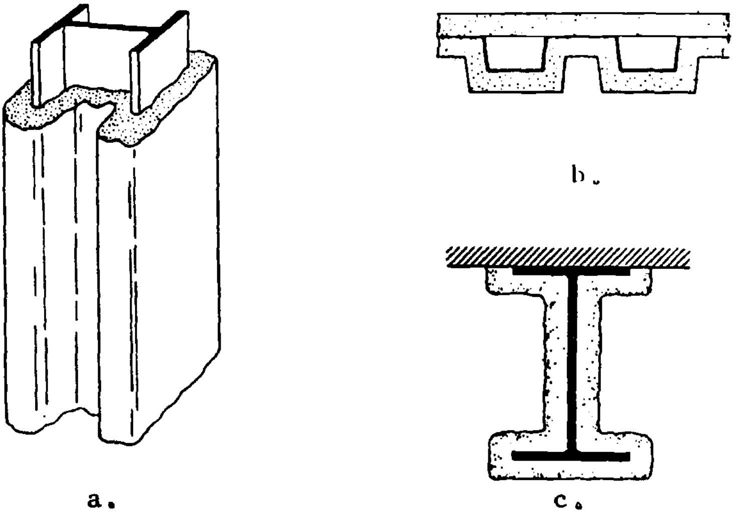


FIG. 2—*Direct contact fire protection:* (a) *column,* (b) *floor deck, and* (c) *beam.*

Fire Resistive Coverings

The wide use of modern steel-framed buildings has fostered the development of lightweight fire resistive coverings. Although steel is noncombustible, it must be protected from unsafe temperatures developed in intense fires, which may cause loss of its structural strength resulting in structural failure.

For many years structural steel framing was encased in heavy masonry to provide fire protection. However, recent research and development in fire-protection technology has produced highly efficient, lightweight fire resistive coverings as well as innovative application techniques that afford significant cost savings [5].

Fire protection of steel floor and roof systems and related structural elements can be achieved by two general methods, first, by contact or directly applied fire protection or, second, by membrane fire protection.

In contact fire protection (Fig. 2) the fire resistive covering or coating is spray-applied directly to the surfaces of the structural components. In floor and roof systems (Fig. 3), for example, the sprayed fire resistive material is applied following the contour of the underside of the formed steel decking and exposed surfaces of the supporting steel.

In membrane fire protection (Fig. 4) a fire resistive barrier is created by applying the fire resistive material as a ceiling below the floor or roofs, or by encasing the individual columns or beams and trusses.

There are three basic types of fire resistive materials:

(1) insulative materials,
(2) energy absorbing (ablative) materials, and
(3) intumescent coatings.

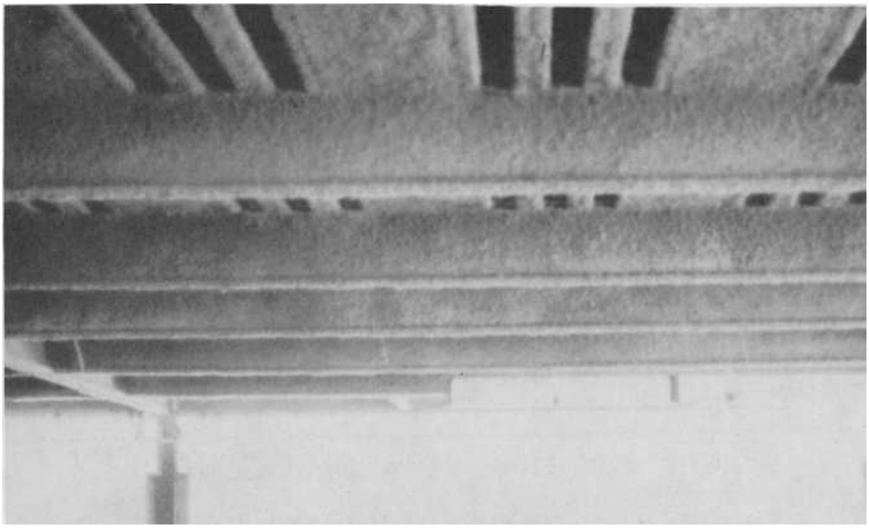


FIG. 3—*Sprayed fire resistive material applied following contour to steel floor deck and beams. Photo courtesy of United States Mineral Products Co.*

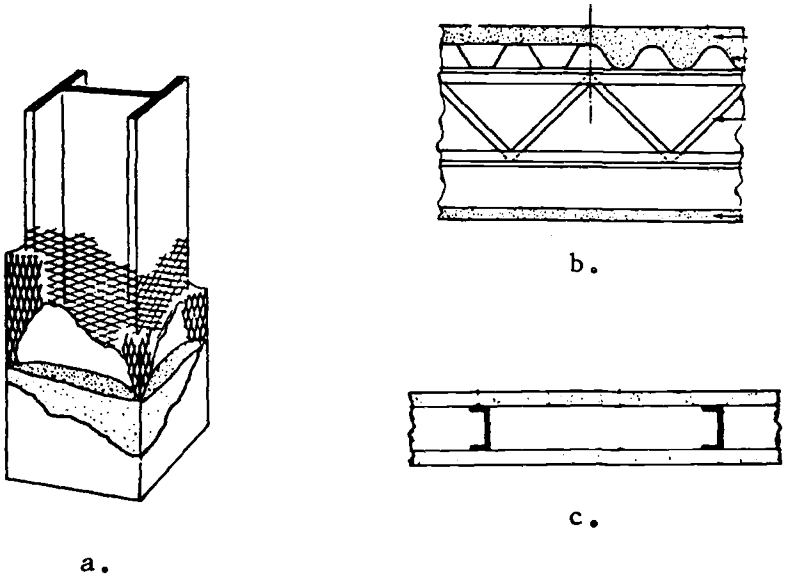


FIG. 4—*Membrane type fire protection:* (a) *column,* (b) *suspended ceiling, and* (c) *walls or partitions. Figure courtesy of the American Iron and Steel Institute.*

Most of the commonly used materials are actually combinations of the first two types since they contain varying proportions of insulative and energy absorbing materials. Intumescent coatings also absorb small amounts of energy when heated. The most widely used insulating materials with excellent thermal qualities are mineral fibers and expanded aggregates, such as vermiculite and perlite. Commonly used energy absorbing materials are gypsum and portland cement, which release water when heated. Magnesium oxychloride is also used but in limited quantities because of its much higher cost.

The following is the process whereby water is released on heating of the fire protection materials

$$\underset{\text{gypsum}}{2CaSO_4\cdot 2H_2O} \xrightarrow[\text{heat}]{} (CaSO_4)_2\cdot H_2O + 3H_2O$$

$$3Mg(OH)_2\cdot MgCl_2\cdot 8H_2O \xrightarrow[\text{heat}]{} 3MgO + MgCl_2 + 11H_2O$$

$$\underset{\substack{\text{magnesium}\\ \text{oxychloride}}}{5Mg(OH)_2\cdot MgCl_2\cdot 8H_2O} \xrightarrow[\text{heat}]{} 5MgO + MgCl_2 + 13H_2O$$

Most contact fire resistive coverings used are either of the sprayed mineral fiber or cementitious types. The sprayed mineral fiber fire resistive coatings are blends of mineral fibers and inorganic binders, which are applied directly to the surface being protected. The fibrous material is blown through a special spray gun that combines fibers, air, and water at the nozzle (Fig. 5). The material is deposited as an insulating blanket in the continuous application following the contour of the formed steel deck and beams to the required thickness at the rate of 1.1 to 1.4 m^3/h (40 to 50 ft^3/h). The dry density of the applied material generally ranges from 190 to 240 kg/m^3 (12 to 15 lb/ft^3). In addition to their excellent thermal insulating qualities, these materials have high sound absorption properties. Until recently, asbestos was a component of the mineral fibers blend. However, because of potential health hazards, present products are made of rock or slag mineral wool fibers and contain no asbestos.

The principal cementitious type of sprayed fire resistive material consists of expanded vermiculite aggregate, hydraulic binders, such as gypsum or clay, and a foaming agent. The material is premixed with water to a plaster consistency and then machine applied directly to the steel surfaces. Dry densities of the cementitious covering range from 290 to 385 kg/m^3 (18 to 24 lb/ft^3).

Intumescent mastic coatings are applied in thicknesses up to 6 mm (¼ in.). When exposed to the heat of a fire, a series of chemical reactions (see Fig. 1) occur that release cooling gases that counteract heat as well as generate a thick carbonaceous foam insulation. An intermediate layer of glass fiber

FIG. 5—*Workers spray steel structural members with fire resistive material. Photo courtesy of the United States Mineral Products Co.*

reinforcement is generally used to control the degree of expansion and provide cohesiveness to the intumescence. The increase in thickness, which may range from five to ten times the original coating thickness, is illustrated in Fig. 6. Dry density of the intumescent mastic coating is about 800 kg/m^3 (50 lb/ft^3).

Test Method

Buildings of fire resistive construction consist of elements that have been assigned fire resistance ratings expressed in hours. The hourly ratings by which the degree of fire resistance is expressed are outlined in ASTM Fire Tests of Building Construction and Materials (E 119-82).

This test method evaluates the ability of a specimen of the structure to act as a barrier to the spread of fire and to confine it to the areas of origin. Fire resistance ratings expressed in hours are assigned to the assembly or component on the basis of the time that it is able to withstand exposure to the standard fire before a condition of failure is reached. In judging when an assembly, such as floors, roofs, beams, columns, and walls no longer act as a barrier in a test, such criteria as structural capability under full load, limiting steel temperatures, passage of excessive heat, flame, or hot gases through the assembly may be used.

Proprietary fire resistive coverings that have been successfully tested in hundreds of assemblies at the ULI are published annually in Ref *6*, which contains hourly ratings for beams, columns, floors, roofs, wall, and partitions. Factory Mutual Research in their *Approval Guide* [*4*] lists tested as-

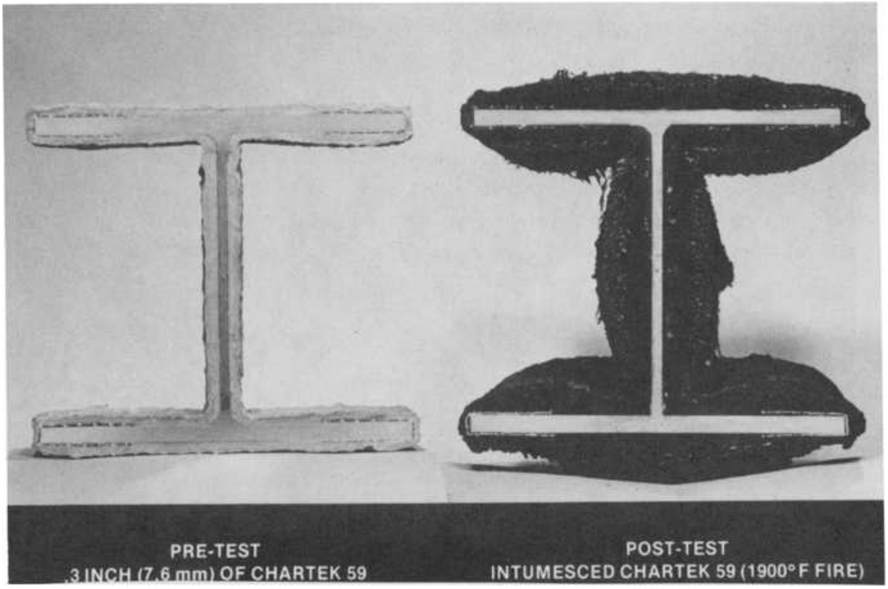


FIG. 6—*Intumescent coating before and after heating in 1000°C (1900°F). Fire pretest thickness 7.6 mm (0.3 in.). Photo courtesy of Avco Specialty Materials Division.*

semblies in the section, "Building Material and Construction." Listed designs are identified in the ULI *Fire Resistance Directory* [*6*] with an alphanumeric design number. The prefix letter designates the type of construction, and the three digit number designates the type of fire resistive covering. For example, prefix letters:

A and D	floor-ceiling designs with steel form floor,
P	roof ceiling designs, and
X	column designs.

Membrane protection uses numbers from 0 to 500. Contact (direct-applied) protection uses the 600 series for miscellaneous materials including intumescent mastics, the 700 series for cementitious materials, and the 800 series for sprayed fiber fire resistive coverings.

Summary

Fire resistant coatings are used to provide fire protection to a variety of constructions.

Fire retardant paints may be applied to wood or cellulosic building materials to reduce combustibility and the surface flame spread. Thicker fire retardant coatings may be applied to wood frame construction in new and retrofit applications to provide fire resistant construction.

In steel frame construction lower density spray-applied fibrous or cementitious materials may be applied to protect steel floors and roofs and beams, typically concealed in plena by suspended ceilings or exposed to view, but out of reach. Such coatings may also be applied to concrete structures to enhance their fire resistive properties.

Higher density cementitious and intumescent mastic coatings are used on steel framing when the application may be subject to severe mechanical abuse and weather, such as in petrochemical and nuclear power plant installations.

References

[*1*] Vandersall, H. L., *Fire Resistance Through Phosphorus-Catalyzed Intumescence,* Monsanto Company.

[*2*] Saunders, H. J., "Flame Retardants," *Chemical and Engineering News,* April 1978.

[*3*] *Building Materials Directory,* Underwriters Laboratories Inc., Northbrook, Ill., 1982.

[*4*] *Approval Guide of Equipment Materials and Services for Conservation of Property—Factory Mutual System,* Norwood, Mass., 1982, pp. 425–426.

[*5*] *Fire Resistant Steel-Frame Construction,* American Iron and Steel Institute, Washington, D.C., 1974.

[*6*] *Fire Resistance Directory,* Underwriters Laboratories Inc., Northbrook, Ill., 1982.

Frank M. Stumpf[1]

Spray-Applied Fibrous Material Fire Resistive Coatings

REFERENCE: Stumpf, F. M., "**Spray-Applied Fibrous Material Fire Resistive Coatings,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 14–23.

ABSTRACT: Mineral fiber compositions for spray-applied fire resistive coatings to buildings are factory mixed products consisting of manufactured inorganic fibers and proprietary binders. Air setting, hydraulic setting, and ceramic binders are used singly or in varying combinations and quantities depending on the use for which the product is designated.

The fibrous materials most commonly used for fireproofing generally range in applied density from 0.2 to 0.6 g/cm^3 and range in applied thicknesses from 1.0 to 6.0 cm on decks and up to 8.0 cm on beams and columns. The spraying process is generally performed with a specially designed machine that feeds the dry mineral fiber composition to a spraying nozzle where the fiber mixture is enveloped with water as it is sprayed onto the surface to be protected. Fire resistant characteristics and other important properties such as insulation and acoustics, and resistance to air erosion and corrosion are discussed.

KEY WORDS: spray applied, fibrous material, mineral fiber, fire resistive, insulative, acoustical, retrofitting, fire resistive coatings

Sprayed fibrous materials have been used as thermal insulation and acoustical treatments since 1920. Their importance as fire resistive materials, however, did not develop until the 1950s with the advent of lightweight cellular steel floor construction for high-rise buildings. The resultant demand for lightweight fireproofing materials brought sprayed fiber products to a position of major importance in the construction industry. This was further enhanced by the continued boom in high-rise building development during the 1960s and 1970s.

Mineral fiber compositions for spray-applied fire resistive coatings to buildings are factory mixed products consisting of manufactured inorganic fibers, proprietary cement-type binders, and other additives in low concentrations to promote wetting, set, and dust control. Air setting, hydraulic setting, and ceramic setting binders are used in varying quantities and combina-

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tions or singly, dependent on the particular intended applications. The major use of sprayed mineral fiber for fire protection is to protect structural steel columns, beams, and both floor and ceiling, and roof constructions that are usually enclosed with other building finishing materials.

Fibers suitable for fire protection application are derived from a number of inorganic materials, which in the past have included asbestos, rock wool, slag wool fiber, and other ceramic fibers. As used today for spray applications, mineral fiber compositions contain no asbestos and are free of crystalline silica. The bulk of the products manufactured commercially are derived from either rock or slag. These fibers are manufactured at temperatures in excess of 1371°C (2500°F) and are resistant to any alkaline effect of the binder systems. The compositions have pH values normally between 8 and 11 and a water soluble chloride ion content less than 100 ppm.

Method of Application

Mineral fiber coatings are sprayed directly onto rigid flat or contoured surfaces, such as steel structural members, or to surfaces wrapped with structural reinforcement, such as metal lath. All surfaces to be coated must be free of dirt, grime, grease, oil, loose paint, and rust or any other condition that would prevent satisfactory bonding and proper adhesion. Sprayed mineral fiber is applied to most surfaces without the use of priming adhesive. In some cases, however, such as certain painted floor sections, and structures subjected to wetting and flexing, such as roof decks, a priming adhesive may be required. This may be a water-emulsion type latex or solvent-based priming adhesive. The adhesive is either brushed, rolled, or sprayed onto the substrate, and before the adhesive is dry, one or more layers of the fibrous composition are sprayed onto the surface.

Wood surfaces require the application of a metal lath or mesh to properly receive the sprayed mineral fiber coating.

The spraying process is performed with specially designed machinery that feeds the dry mineral fiber composition to a spraying nozzle, where the fiber mixture is mixed with water as it is sprayed onto the surface to be fire protected. Factory-mixed fiber is received dry at the job site in bags usually weighing 18 to 23 kg (40 to 50 lb). The fiber is placed in the spraying machine, which opens and fluffs the nodules and feeds the material at a uniform rate to the conveying system. Pneumatic blowers convey the fiber in the dry state through a hose to the spray gun. Water is introduced at the gun and atomized, and the water mist envelops and combines with the dry fiber and binder before they reach the surface to be treated. The fibrous mat is built up in a uniform layer in thicknesses ranging from 0.6 to 8.0 cm (0.25 to 3.0 in.), depending upon the use and specification. Fiber feed rate may vary from 1.8 to 18 kg/min (4 to 40 lb/min). The applied product primarily is left untamped as is, or may be tamped or rolled if a finished texture or appearance is desired.

Finished surfaces are sprayed with water to lock in any loose fiber and to increase surface hardness. The surface may be also painted or coated with mastics or encrusted with hard surface materials, if so required.

A diagram of the procedure for spray application of mineral fiber to structural steel members in a multistory building is shown in Fig. 1.

Application Equipment

Application equipment is available in various sizes and capacities. Machines may differ in design; however, the fiber is usually conveyed from the hopper to the pneumatic system by screw or paddle conveyors. Metering is accomplished by adjusting the speed of the conveyor device or by varying a gate opening. The fiber is fluffed in the machine in order to improve interlocking of the nodules before entry into the pneumatic system, where the material is conveyed by simple impeller blowers, multiple blowers, or air-

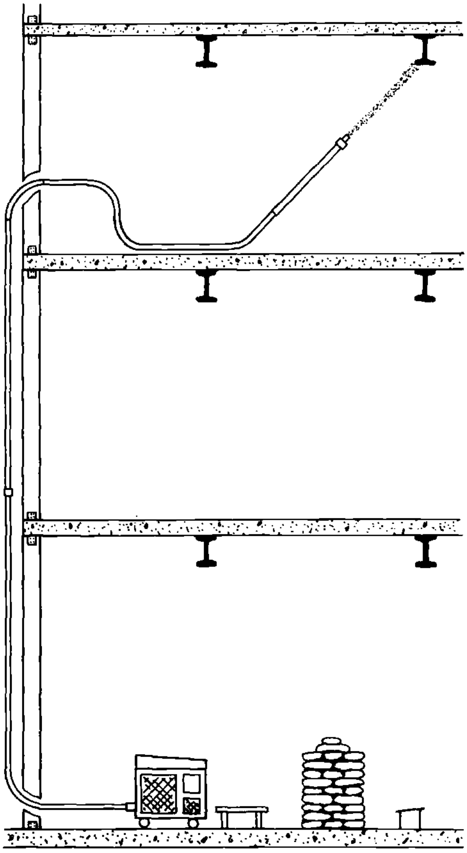

FIG. 1—*Diagram of spray-applied mineral fiber application system.*

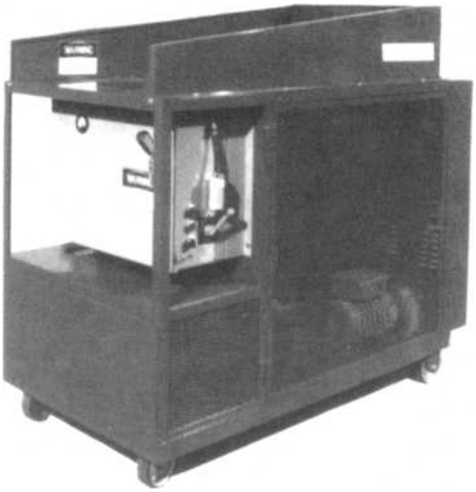

FIG. 2—*Typical application machine for spray-applied mineral fiber.*

locks and positive pressure blowers. A typical application machine is shown in Fig. 2. Hose sizes range from 5 to 7.6 cm (2 to 3 in.) in diameter and lengths from 7.6 to 229 m (25 to 750 ft) with high capacity conveying systems. Material is conveyed vertically as much as 50 stories (in excess of 198 m [650 ft] above the application machinery). Maximum hopper capacity for the loose mineral fiber mix is in the order of 280 L (10 ft^3).

Special nozzles have been designed and engineered to fan out or pinpoint

FIG. 3—*Horizontal spraying of mineral fiber composition.*

FIG. 4—*Vertical spraying of mineral fiber composition using a pole gun.*

the sprayed fiber during application and to efficiently envelop the fiber in a water mist. Thus dust is minimized and the mixture is properly wet just before surface impact. Water flow requirements range from 2.2 to 22.0 L/m (5 to 50 lb/min) at pressures from 275 to 689 kN/m^2 (40 to 100 lb/in.^{2}). Nozzles can be either airless or compressed air type.

Typical applications of mineral fiber composition to steel surfaces are shown in Figs. 3 through 6.

FIG. 5—*Beam and deck construction ready for spraying.*

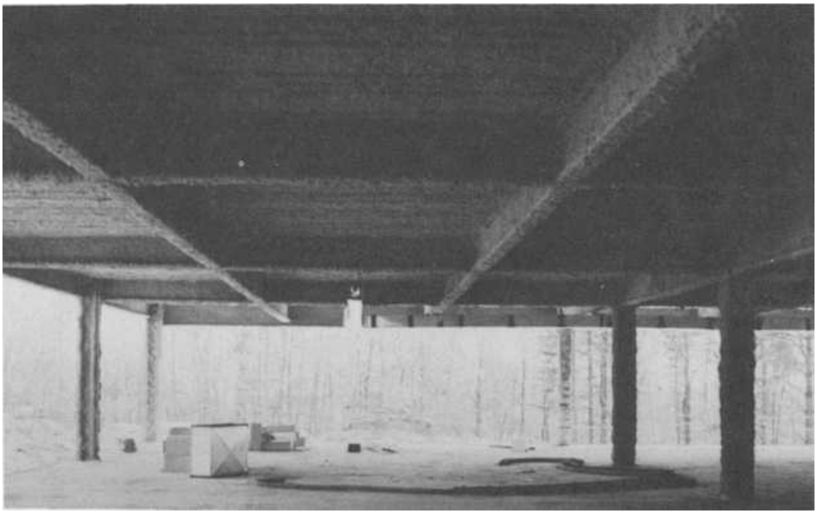

FIG. 6—*Beam and deck construction after completion of spraying.*

Fire Resistive Properties

Sprayed fibers have been extensively tested for fire retardancy in accordance with the ASTM Fire Tests of Building Construction and Materials (E 119), or their equivalent, in the United States and throughout the world. Fire resistance ratings have been obtained for virtually all types of cellular and fluted steel decks, concrete decks, beams, joists, and columns in hourly increments from 1 to 6 h.

Mineral fiber compositions most commonly used for fire protection generally range in applied densities from 0.2 to 0.6 g/cm^3 (10 to 36 lb/ft^2) and range typically in applied thickness from 1 to 6.4 cm (0.25 to 2.5 in.) on decks, from 1.3 to 5.0 cm (0.5 to 2.0 in.) on beams and up to 8 cm (3 in.) on columns. Thickness requirements are based generally upon the specified fire resistance hourly ratings.

In the ASTM Test for Surface Burning Characteristics of Building Materials (E 84) sprayed fiber compositions generally do not exceed flame and smoke values of 20. Actual fire service records have established an excellent performance history for sprayed fiber products.

In one incident in a building under construction, an area was subjected to such intense heat that dense materials applied to the columns and spandrels cracked and spalled. However, the sprayed fiber applied to a steel deck girder and beam appeared unaffected. Upon removal of the sprayed fiber, examination showed that neither the paint on the structural members nor the galvanizing on the steel deck had even been discolored by the fire.

Sprayed fire resistive materials are primarily insulative and do not depend upon ablation or release of water of crystallization for their performance, thus the integrity of their composition remains relatively unaltered upon exposure to high temperatures. This phenomenon was demonstrated in a full-scale ASTM E 119 column test, where a column reached its limiting temperatures at 2 h and 13 min. The same column was allowed to cool down to ambience and retested again under the same ASTM E 119 time-temperature conditions. The second trial resulted in an end point of 2 h and 3 min [*1*].

Full-scale testing equivalent to ASTM E 119 is conducted in many countries throughout the world. Sprayed-fibrous fire resistive product has been tested under full-scale conditions in the United States at many different laboratories, and in Canada, England, Germany, France, Belgium, Holland, Australia, Japan, and so forth.

Additional Properties

Insulative

An important function of sprayed fiber fireproofing is its insulative property. The thermal conductivity (k-factor) may range from 0.039 to 0.048 W/m/K (0.27 to 0.33 Btu/h/ft^2 °F/in.). This additional function is well illustrated in its use at the World Trade Center Towers. The unique design of these structures positioned all the columns at the exterior of the building, requiring that the temperature of the columns be controlled within a narrow range to prevent excessive dimensional change. Of particular concern was the possibility of differential column expansion between the sunny and shady side of the building that could result in a floor level change of as much as 50.8 m (2 in.). The application of sprayed fiber in this case met the design requirements for both fireproofing and insulation.

These high insulating values are also important in applications to roof decks and where cells in cellular decks are used as ducts for the flow of heated and cooled air, and also where floor-to-floor temperature differences exist, or where zoned temperature control within a building is desired.

Fireproofing with sprayed fiber to spandrel beams and secondary beams, which abut the building perimeter area, also have added insulating value, as these members frequently are the cause of heat loss and gain. Many structural members may be also subjected to condensation or dripping if treated with a material having poor thermal insulating properties, thus requiring a separate application of insulation material. The added advantage is also realized where exposed floors or roofs can be both fireproofed and insulated with a single sprayed fiber application, as in setbacks and soffit areas.

Acoustical

The excellent acoustic properties of fibrous fireproofing materials obviate the need for acoustical ceiling materials such as tiles. The acoustical efficiency of suspended luminous plastic ceilings is improved by its use. Applications of 12.7 mm (½ in.) on fluted decks and beams result in noise reduction coefficients of 0.85 and absorption factors at 500 Hz of 0.75. Also, the sound transmission over mobile partitions is diminished as the sound passing through the suspended acoustical ceiling is absorbed by the fibrous fireproofing rather than reflected down into an adjoining area. In many areas of commercial structures, where suspended acoustical ceilings are either not practical, or not required, fibrous fireproofing material may be left exposed, attractively finished with a texture coat of sprayed fiber, and may be spray painted with nonbridging paints to prevent loss of acoustical efficiency.

Resistance to Air Erosion

With the increased use of plenum chambers in which the contact fireproofing is exposed as a part of the air flow system in multistory buildings, it is important to know that loose individual fibers do not contaminate the air filtering system. Extensive tests on most sprayed fiber products showed that the air erosion, at velocities as high as 365 m/min (1200 ft/min) impinging directly on the fiber, is negligible. Some sprayed fiber manufacturers may recommend the use of a surface sealer to further knit together the surface fibers.

Corrosion Resistance

An important benefit of certain sprayed fiber products is that their chemical properties are such that they may actually protect the steel member from corrosion. Tests show that the value of this corrosion protection is equivalent to the field coat of paint normally applied to structural steel members.

Resistance to the Elements

The ability of a sprayed fiber fireproofing to withstand driving rain was amply demonstrated during the construction of the World Trade Center Towers. At this site, the 365-m (1200-ft) long columns protected with the fibrous product, were subjected to torrents of cascading rainwater, before the columns were enclosed with the protective metal sheets, with no deleterious effects on the coating.

Retrofitting of Wooden Structures

An application that may have important potential is the retrofitting of combustible structures with wood framing to provide them with increased fire resistance. Fire tests have been conducted on wood framing assemblies in which expanded metal lath was applied to the wood joists that were then sprayed with 2.54 mm (1 in.) or more of fiber. These tests showed that sprayed fiber will provide at least 2 h of fire endurance. Application of sprayed fiber to protect wood joists has been accomplished on a number of old cathedrals.

Tests and Standards

The most common test to evaluate the fire resistance of walls, floors, beams, and columns is ASTM E 119 where the exposed surfaces are subjected to a fire temperature of 538 °C (1000 °F) at 5 min and 927 °C (1700 °F) at 1 h. Concern in the petrochemical industry has been for a higher intensity fire exposure. Sprayed fiber fire resistive coatings have been tested using high intensity flames reaching temperatures of 1093 °C (2000 °F) in 5 min with satisfactory performance in that no spalling or other failure occurred during 2 h of exposure.

Another large-scale test used to evaluate fire exposure performance of sprayed mineral fiber compositions is ASTM E 84. This test measures flammability under controlled laboratory conditions and was designed primarily to evaluate flame and smoke characteristics. For mineral fiber compositions it is useful for assessing contribution of any organic constituents to these factors.

In addition to the previously mentioned tests for fire protection performance, laboratory tests have also been conducted by manufacturers of spray-applied mineral fiber compositions related to quality control, physical properties, adhesion, and serviceability. The most important of these are

(1) Tests for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members (E 605-77),

(2) Corrosion of Steel by Sprayed Fire-Resistive Materials Applied to Structural Members (E 937),

(3) Test for Effect of Deflection of Sprayed Fire-Resistive Material Applied to Structural Members (E 759-80),

(4) Test for Effect of Impact on Bonding of Sprayed Fire-Resistive Material Applied to Structural Members (E 760-80),

(5) Test for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 736-80),

(6) Test for Compressive Strength of Sprayed Fire-Resistive Materials Applied to Structural Members (E 761-80), and

(7) Test for Air Erosion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 859-82).

Conclusions

The following favorable aspects are listed for sprayed mineral fiber as a fire resistive coating for structural members, ceilings, and decks in large multistory buildings.

1. Fast application rates—as much as 18 kg (40 lb), approximately 0.07 m^3 (2.5 ft^3) applied per minute per machine; no time delays between coats; complete application in one pass; up to 50 floors may be treated from a single machine location.

2. Quick job startups and shutdowns—approximately 15 s.
3. Applicable to any contours.
4. Fast drying—no delays in application of finishing materials.
5. Chemically inert—generally resistant to most environments.
6. Flexibility of coating makes for no shrinkage or cracking.
7. Also affords thermal and acoustical values and some condensation control in addition to fire resistance.
8. Lightest weight per 25.4 mm (1 in.) of coating and per 1 h of fire retardant rating.

Restrictions for the use of mineral fibers are as follows:

1. The requirement for specially designed pneumatic application equipment.
2. Must be applied to surfaces that are above freezing temperatures.
3. Lower density materials are not to be left exposed or unprotected in areas subjected to abrasion or damage, or to exterior environmental conditions.

Reference

[*1*] "Column Protected with Sprayed Fiber," Underwriters Laboratories Inc. Report, File R3749-38 and R3749-39, March 1976.

DISCUSSION

Recorded Discussion

Chris Magdalin[1]—You mentioned that spray-applied fibers were evaluated in a hydrocarbon-type fire and compared to ASTM E 119 time-temperature fire and had no thermal shock differences in respect to spalling and delamination. Could you tell me what the fire resistance was at equivalent thicknesses from the hydrocarbon exposure as compared to an ASTM E 119 exposure?

F. M. Stumpf—It was less. I remember one number with a W10X49 column in an ASTM E 119 exposure. A 31.8-mm (1 ¼-in.) thick application went 122 min. In the hydrocarbon fire, a 38-mm (1 ½in.) thick application on a W10X49 column went 119 min, so here we see the difference. Now there were others, but I do not recall them.

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[1] Carboline Company, St. Louis, Mo. 63149.

Robert H. White[1]

Use of Coatings to Improve Fire Resistance of Wood

REFERENCE: White, R. H., "**Use of Coatings to Improve Fire Resistance of Wood,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 24-39.

ABSTRACT: Currently used fire retardant coatings for wood products reduce flame spread; they are not designed specifically to provide fire resistance. Fire resistive coatings designed for steel and foam plastics generally are not recommended for wood. Small nonload-bearing fire resistance tests were conducted in this study to determine the fire resistance of eight commercially available fire retardant and fire resistive coatings when applied to a wood product.

Coated plywoods over a foam plastic substrate were tested in a small-scale vertical exposure furnace in accordance with ASTM Fire Tests of Building Construction and Materials (E 119-82). The results were the times for the temperature rise to reach an average value of 139°C (250°F) or a maximum value of 181°C (325°F) at the plywood/foam-plastic interface. Uncoated plywoods were tested as controls.

Fire retardant coatings improved the times for plywood specimens by up to 900 s, and fire resistive coatings showed a 240- to 2640-s improvement over uncoated plywood. Coatings significantly improved the fire resistance of a wood product. The fire resistance data reported in this paper should aid in future considerations of fire resistive coatings in wood construction.

KEY WORDS: fire resistant coatings, fire retardant coatings, fire resistance, fire tests, wood, plywood

The fire resistance of traditionally designed structural wood members has been sufficient to meet code requirements because of wood's low thermal conductivity; production of an insulative char layer as it burns; the solid, generally rectangular, cross section of the structural wood member; and the generally conservative nature of traditional wood construction. However, progress in wood engineering and better understanding of the basic properties of wood has improved wood utilization in structural wood assemblies. Examples of these products are glued laminated beams, wood trusses, sand-

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[1] Research forest products technologist, U. S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, Wis. 53705.

wich panels, glued plywood beams, and prefabricated wood joists [*1*]. In these and similar applications, there may be a need to improve fire endurance. In addition, changes in the occupancy of a building or new requirements in the building codes may increase the required fire resistance rating in an existing structure.

Fire resistive coatings add fire resistance to the substrate. Fire resistance is the property of a material to withstand fire or give protection from it. Fire resistance of elements of buildings is characterized by the ability to confine a fire or to continue to perform a given structural function or both. Commercial coatings have been available for some years to improve the fire resistance of structural steel. More recently, they have been developed for foam plastics. However, no coatings specifically designed for improving the fire resistance of wood are currently available. Fire retardant coatings provide comparatively low flammability or flame spread properties to the substrate. Flashover, or the sudden simultaneous ignition of most combustibles in a room, signals the start of a fully developed fire. Existing coatings for wood are fire retardants that reduce flame spread in the preflashover fire mode, as opposed to fire resistant coatings that improve fire endurance of the protected substrate beyond the time of flashover.

Existing published data on the fire resistance of coated wood are limited and inconclusive. Coated wood beams or columns have been tested in Europe and Japan to determine the effect of coatings on rate of charring [*2–5*]. Sandwich panels with and without mastic fire resistive coatings have been tested for fire endurance [*6*]. In Canada, a wood floor and ceiling assembly coated with cementitious material on an expanded metal lath and a mastic coating have a 1½-h unrestrained assembly rating [*7*]. In most cases, only one specimen of a given coating was tested. Thus, statistically reliable data that conclusively evaluate the effect of fire retardant or fire resistive coatings on the fire resistance of wood are not available in the published literature.

In recent years, building codes have required foam plastics to be fully protected from the interior of the building by a thermal barrier. This thermal barrier must limit the average temperature rise of its unexposed surface to 139°C (250°F) for at least 900 s of fire exposure in accordance with ASTM Fire Test of Building Construction and Materials (E 119-82). This study on coatings is a follow-up to a previous study on wood-based panel products as possible thermal barriers [*8,9*].

The objective of the work reported here was to obtain performance data showing the effect of coatings applied to a wood product in improving the fire resistance. Four fire retardant coatings and four fire resistive coatings (Table 1) were evaluated for their ability to improve the fire resistance of plywood. All coatings were commercially available. It is hoped that the results of this work will encourage the development of fire resistive coatings specifically formulated for wood.

TABLE 1—*Description of coatings.*

Designation	Coating
	FIRE RETARDANT COATINGS
A	flat, latex emulsion, intumescent coating, applied at Forest Products Laboratory
B	high build, two-component, catalytic, epoxy, intumescent coating, applied at Forest Products Laboratory
C	catalytic polyurethane intumescent varnish over one coat of a clear single-component sealer, applied at Forest Products Laboratory
D	flat, alkyd, intumescent coating, applied at Forest Products Laboratory
	FIRE RESISTANT COATINGS
E	water-based, single-component asbestos-free flexible mastic coating, troweled on at Forest Products Laboratory
F	sprayable, ablative, catalyst-cured coating using a polymer binder and containing no free water, sprayed on by manufacturer
G	mineral fiber and binder, sprayed on by manufacturer
H	ablative, epoxy, room temperature curing, two-component intumescent mastic coating approved for exterior use, sprayed on by manufacturer
NC	no coating

Procedure

As in previous tests [*8*], the plywood was tested over a foam-plastic substrate in a small vertical furnace. Satisfactory performance was based on the times until the 139/181°C (250/325°F) temperature rise criteria of ASTM Method E 119-82 were satisfied at the interface of the plywood and the foam plastic.

Different thicknesses of coatings were tested on three thicknesses of plywood as shown in Table 2. Most tests were replicated three times. The original experimental design included:

(1) one thickness of four fire retardant coatings on nominal 16-mm (⅝-in.) plywood,

(2) two thicknesses of four fire resistive coatings on nominal 16-mm (⅝-in.) plywood,

(3) one thickness of one fire retardant coating on nominal 6- and 19-mm (¼- and ¾-in.) plywood,

(4) one thickness of one fire resistive coating on nominal 6- and 19-mm (¼- and ¾-in.) plywood, and

(5) uncoated nominal 6-, 16-, and 19-mm (¼-, ⅝-, and ¾-in.) plywood.

Preparation of the Specimens

Plywood specimens were conditioned to equilibrium moisture content at 23°C (73°F) and 50% relative humidity before coatings were applied. After

TABLE 2—*Average test results for fire retardant coatings.*

					Time to 139/181°C[a]		
					Total		
Coating Designation	Number of Tests	Number of Coats	Dry Coating Thickness, mm	Dry Coating Weight, g/m^2	Mean, s	COV[b], %	Improvement[c], s
			6-MM (¼-IN.) PLYWOOD				
NC	3	0	0.0	0	210	7	0
A	3	5	0.5	720	350	3	150
D	1	1	0.1	130	360	...	140
D	1	2	0.2	300	390	...	180
D	1	3	0.3	460	470	...	260
D	1	4	0.4	600	450	...	230
D	1	5	0.5	760	480	...	290
			16-MM (⅝-IN.) PLYWOOD				
NC	6	0	0.0	0	670	2	0
A	3	1	0.1	140	820	1	160
A	3	5	0.5	670	1040	6	370
B	3	1	0.1	260	780	1	120
B	3	5	0.5	920	1160	4	500
C	3	8	0.6	910	1260	1	590
D	3	5	0.5	920	1580	3	920
			19-MM (¾-IN.) PLYWOOD				
NC	3	0	0.0	0	870	2	0
A	2	1	0.1	120	990	9	120
A	3	5	0.5	670	1270	3	400
D	2	1	0.1	190	1310	2	440

[a] Time for unexposed surface of plywood to reach average of 139°C (250°F) or maximum of 181°C (325°F) above initial temperature.

[b] Coefficient of variation.

[c] Improvement over the time for uncoated plywood. Calculations are based on the individual test results; this may not be the same as the difference in average times.

the coatings were applied, specimens were reconditioned for a minimum of 30 days. The differences in weight and thickness between the specimen before coating and the coated specimen at the time of testing were recorded as the dry coating weight and the dry coating thickness.

The 508- by 508-mm coated-plywood specimen and a foam-plastic slab were screwed to a wood frame (Fig. 1). Five 30-gage iron-constantan thermocouples were attached to the unexposed side of the plywood. Thermocouples were located at the center of the panel and at the center of each quadrant.

Materials

The eight coatings[2] are described in Table 1. Coatings were selected so a range of different types of coatings was tested. Coatings A through D are fire

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[2] The use of commercial products in this study was for the convenience of the government. Such use does not constitute an official endorsement or approval by the U. S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

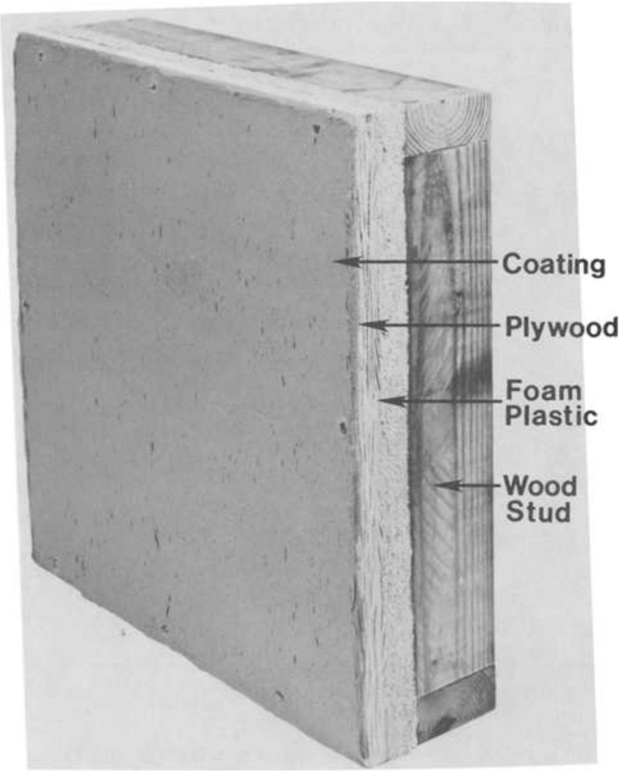


FIG. 1—*Coated test specimen on wood frame.*

retardant coatings designed to reduce the flame spread of wood substrates as measured in the ASTM Test for Surface Burning Characteristics of Building Materials (E 84-77). The fire resistive coatings were designated as Coatings E through H. Coating E is designed to halt fire propagation in grouped electrical cables. Coatings F, G, and H are designed to provide thermal or fire protection to steel or foam plastics.

The sanded southern pine plywood was graded "PS 1-74, Exterior, A-C, Species Group 1." The average measured thicknesses of the nominal 6-, 16-, and 19-mm (¼-, ⅝-, and ¾-in.) plywood panels were 7.3, 16.2, and 19.1 mm, respectively. The plywood had an oven-dry density of 460 ± 60 kg/m^3 and moisture content of 8.7 ± 0.7%.

The foam-plastic slabs were cut from nominal 25.4-mm (1-in.) foam-plastic sheathing. The sheathing had a glass-reinforced polyisocyanurate foam-plastic core with aluminum foil facings. The foam-plastic sheathing had an R-value of 1.3 m$^2 \cdot$K/W and density of 32 kg/m^3.

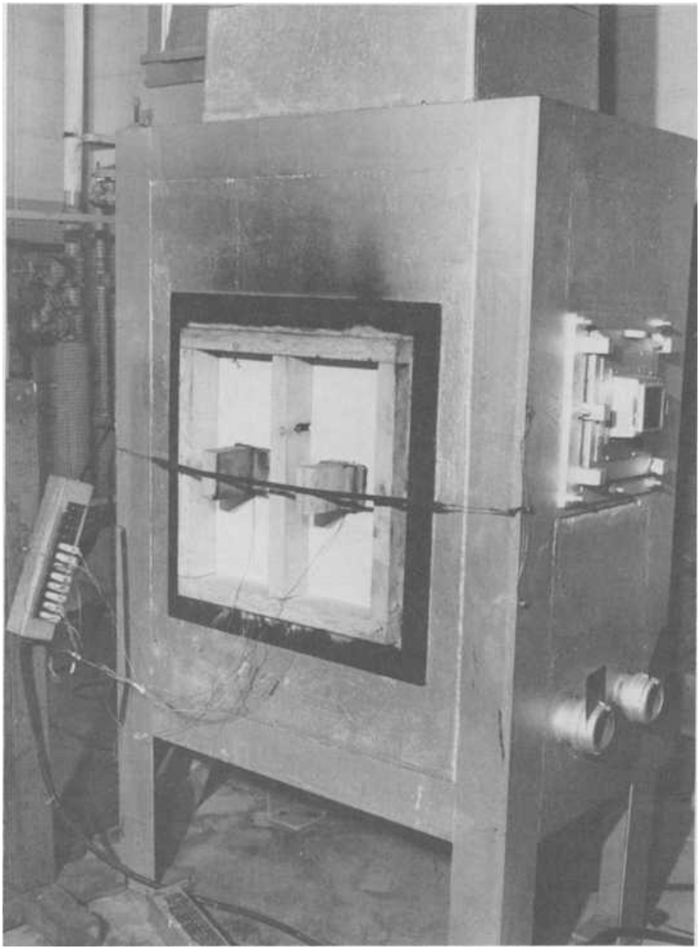


FIG. 2—*Small vertical furnace.*

Equipment

The vertical furnace (Fig. 2) has a 508-mm square opening into which the specimen was inserted. The furnace is equipped with pipe outlets for discharging natural gas into the furnace. Air for combustion was admitted by natural draft through vents at the bottom of the furnace and was distributed with a baffle. A single iron-capped time-temperature curve monitoring thermocouple was located inside the furnace opposite the center of the specimen and 51 mm from the exposed surface of the specimen. The thermocouple was located closer to the specimen than the 152 mm specified in

TABLE 3—*Average test results for fire resistive coatings.*

Coating Designation	Number of Tests	Dry Coating Thickness, mm	Dry Coating Weight, g/m^2	Time to 139/181°C[a]		
				Total		
				Mean, s	COV[b], %	Improvement[c], s
6-MM (¼-IN.) PLYWOOD						
NC	3	0.0	0	210	7	0
F	3	2.9	4940	730	8	530
16-MM (⅝-IN.) PLYWOOD						
NC	6	0.0	0	670	2	0
E	3	1.4	2010	930	4	250
E	3	6.0	8720	1890	6	1220
F	3	1.9	3320	1070	6	400
F	3	2.8	4840	1300	1	640
G	3	12.7	1640	1230	6	560
G	3	34.8	6120	3320	10	2640
H	3	2.6	3550	1690	7	1020
H	3	6.4	8640	3100	3	2420
19-MM (¾-IN.) PLYWOOD						
NC	3	0.0	0	870	2	0
F	3	2.6	5000	1610	1	740

[a] Time for unexposed surface of the plywood to reach average of 139°C (250°F) or maximum of 181°C (325°F) above initial temperature.

[b] Coefficient of variation.

[c] Improvement over the time for uncoated plywood. Calculations are based on the individual test results; this may not be the same as the difference in average times.

ASTM Method E 119-82. This was necessary if the thermocouple was to be located between the specimen and the natural gas pipe outlets. It was assumed that this has no appreciable effect on the results.

Test Procedure

The gas supply of the furnace was regulated so the temperature of the iron-capped thermocouple followed the ASTM Method E 119-82 time–temperature curve during the test. The test was continued until all of the thermocouples at the plywood foam-plastic interface had recorded at least a 139°C (250°F) rise in temperature. An average rise of 139°C (250°F) is one of the limiting performance criteria. The specimen was observed during the test through the two observation ports on the sides of the furnace (Fig. 2).

Results

Numerical Results

For each test, the time was noted when the five thermocouples attached to the unexposed side of the plywood recorded an average temperature rise of 139°C (250°F) and when any one thermocouple recorded a 181°C (325°F) temperature rise. The lesser of the two times is reported as the total time. The mean total times for the four fire retardant coatings on 16-mm (⅝-in.) plywood ranged from 780 to 1580 s (Table 2). The mean total times for the four fire resistive coatings on 16-mm (⅝-in.) plywood ranged from 930 to 3320 s (Table 3). The coefficients of variation for the replicated tests were 10% or less. On average, the coated specimens have a significantly higher total time than the uncoated specimens. Individually, all the coated specimens except the single coat of Coatings A or B were significantly better than the uncoated control specimens. The uncoated 16-mm (⅝-in.) plywood had an average time of 670 s.

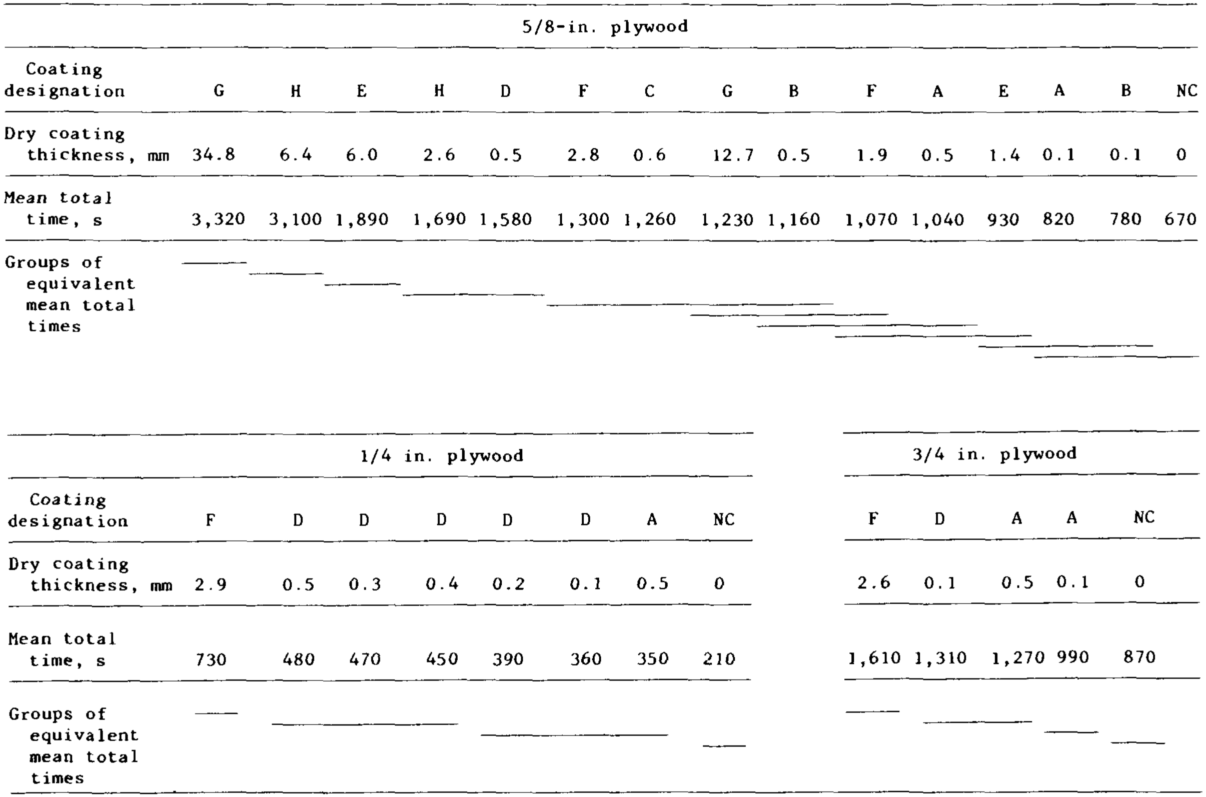
The difference between the endurance time for the coated specimen from the time for the uncoated specimen, which was cut from the same sheet of plywood, was calculated as the improvement caused by the coating. For the four fire retardant coatings, the average improvement with respect to the uncoated 16-mm (⅝-in.) plywood ranged from 120 to 920 s (Table 2). The improvement for the four fire resistive coatings on 16-mm (⅝-in.) plywood ranged from 250 to 2640 s (Table 3).

The average improvements of coated over uncoated plywood increased with the thickness of the plywood.

Visual Observations

Observations of the specimens during the tests were difficult because the natural gas flames from the burner often obscured the view of the specimens. The fire retardant coatings were intumescent coatings that expanded to a thick foamy layer when exposed to heat. For the thicker multiple coated specimens, an increase in thickness up to 75 mm was observed. When the expansion was substantial, the foam would sometimes slip from the top to the bottom of the vertical specimen or fall off the specimen. While substantial parts of the foam sometimes fell off, the base of the foam layer remained attached to the plywood. After continued exposure to the fire, the rest of the foamy layer burned away or fell off. Less expansion was observed on specimens protected with one coat. No expansion of Coating B was noticed when only one coat had been applied. In contrast, 75 mm of intumescence was observed with five coats of Coating B.

The main observation with some of the fire resistive coatings was failure of the adhesion of the coating to the plywood. Small blisters formed on the surface of Coating E, and the coating would crack and parts would come off as the test progressed. Coating F either came loose from the plywood or burned away. Coating G remained intact during the test but was not attached to the plywood when the specimen was removed from the furnace after the test. Coating H expanded and remained attached to the plywood.



5/8-in. plywood															
Coating designation	G	H	E	H	D	F	C	G	B	F	A	E	A	B	NC
Dry coating thickness, mm	34.8	6.4	6.0	2.6	0.5	2.8	0.6	12.7	0.5	1.9	0.5	1.4	0.1	0.1	0
Mean total time, s	3,320	3,100	1,890	1,690	1,580	1,300	1,260	1,230	1,160	1,070	1,040	930	820	780	670
Groups of equivalent mean total times															

1/4 in. plywood							
Coating designation	F	D	D	D	D	D	A	NC
Dry coating thickness, mm	2.9	0.5	0.3	0.4	0.2	0.1	0.5	0
Mean total time, s	730	480	470	450	390	360	350	210
Groups of equivalent mean total times								

3/4 in. plywood				
F	D	A	A	NC
2.6	0.1	0.5	0.1	0
1,610	1,310	1,270	990	870

FIG. 3—*Grouping of mean results that are not significantly different. (Duncan's multiple range test of uncoated and coated plywood results.)*

Comparison of Results

On average, the fire resistive coatings have a significantly higher total fire resistance time than the fire retardant coatings. The fire resistive coatings were thicker coatings than the fire retardant coatings. Fire retardant coatings are only expected to reduce flame spread. The Duncan's multiple-range statistical test was used to rank the total times for the different types of specimens (Fig. 3). Specimen types were grouped together if their mean results were not significantly different. Because the ranking depends upon the thickness of the coating, it is not a ranking of the different coatings.

Effect of Coating Thickness

Performance of a coating improved as the thickness of the coating was increased as shown in Figs. 4 and 5 and Table 4. For fire retardant Coatings A and B, and fire resistant Coatings E, F, G, and H, the increase in time per increase in coating thickness was calculated for replicated data at two thicknesses. The difference in the means for the two thicknesses was statistically significant for each of the coatings.

The increase for fire retardant Coating D is based on singular tests at five coating thicknesses. Based on the variability of other replicated 6-mm (¼-in.)

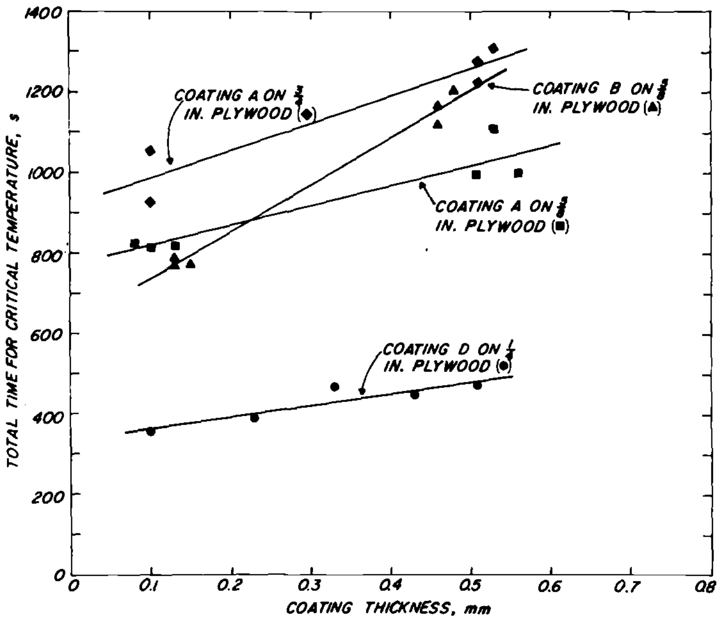


FIG. 4—*Total time versus fire retardant coating thickness.*

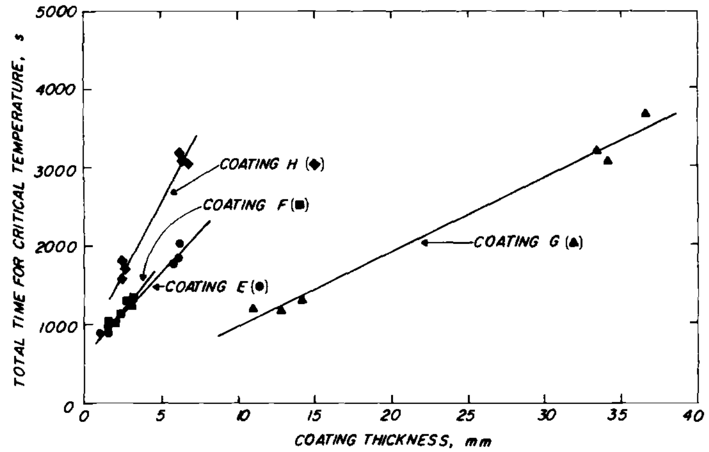


FIG. 5—*Total time versus fire resistive coating thickness.*

plywood tests, the difference between the 0.1-mm-thick and the 0.5-mm-thick Coating D is significant.

For comparison, the increase in time for the uncoated plywood was 70-s/mm increase in the thickness of the plywood.

Effect of Plywood Thickness

In the statistical evaluation of the total times, the plywood thickness by treatment interaction term suggested that the coatings behaved differently on different thicknesses of plywood. This is also shown in the data for the improvements obtained with the coatings. The improvement of the coated plywood with respect to the uncoated plywood increased with an increase in the thickness of the plywood (Fig. 6). See Table 5.

This is because the coatings provide an insulative layer over the plywood

TABLE 4—*Coating thickness.*

Nominal Thickness of Plywood, in.[a]	Coating	Increased Time per Millimetre Thickness of Coating, s/mm
⅝	A	495
. . .	B	1160
. . .	E	206
. . .	F	234
. . .	G	94
. . .	H	363
¾	A	671
¼	D	293

[a] 1 in. = 25.4 mm.

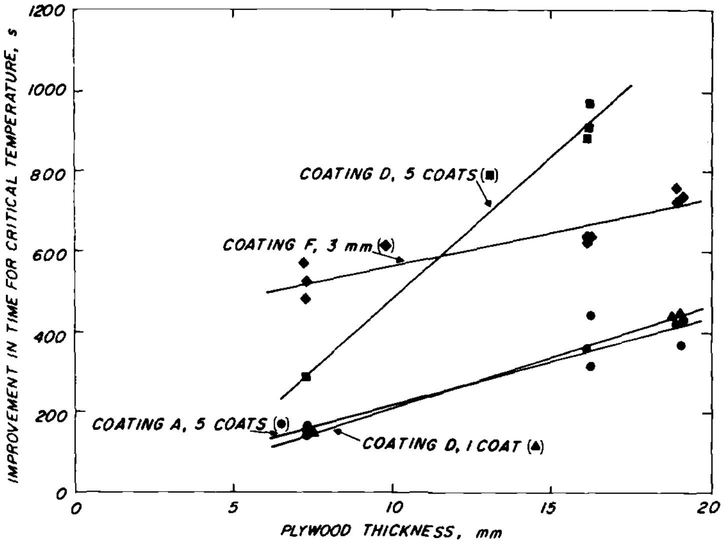


FIG. 6—*Improvement in time versus plywood thickness.*

in addition to delaying the ignition and charring of the plywood. An insulative layer will reduce heat transfer into the substrate. As a result, the time for a temperature rise at a given location in the substrate will be increased. The longer the total time, the longer the insulative layer will improve the performance of the specimen. Because the temperature is recorded at the unexposed side of the plywood, thicker plywood specimens increase the total exposure time. Thus, the improvement shown for insulative coating will increase as the thickness of the plywood is increased.

In addition to plywood thickness, other methodology factors, such as substrate, orientation of specimen, and size of specimen may affect the results. The amount and type of insulation behind the plywood has an effect on the results [*8*]. In previous tests, the results were greater for uncoated plywood when tested over calcium silicate than when tested over foam plastics [*9*].

TABLE 5—*Plywood thickness.*

Coating	Thickness of Coating, mm	Increased Time per Millimetre Increase in Thickness of Plywood, s/mm
A	0.5	22
D	0.1	26
D	0.5	71
F	2.9	17

Tests were conducted on vertical specimens only. Floor ceilings and other horizontal specimens are generally tested for fire exposure from below. Thus, a horizontal orientation of the specimen may have a detrimental effect on results for coated plywood when there is poor cohesion or adhesion of the coating. The 9-m^2 fire-exposed area required by ASTM Method E 119-82 for performance of protective membranes in wall assemblies would better test the ability of a protective membrane or thermal barrier to remain in place than did the small-scale tests performed in this study.

Discussion

Fire resistant coatings have potential for use in several situations. Coatings can be used to improve the fire endurance of the new structural wood products mentioned in the introduction. The coatings can improve the finish rating of panel products used as a thermal barrier for foam plastics. In addition, the development of analytical procedures for predicting the fire resistance of large-timber members should make it more feasible to obtain acceptance for fire resistive coated timber members when a specific fire rating is required.

In addition to the degree of thermal protection, there are other things to consider before using a fire resistive coating. These include properties in areas of (1) durability at normal temperatures, (2) durability at elevated temperatures, (3) smoke and toxic gas hazard, and (4) fire spread and structural stability [*10*]. ASTM test standards are being developed to determine the performance characteristics of sprayed-applied fireproofing [*11*]. Published standards include ASTM Tests for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members (E 605-77), Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 736-80), Effect of Deflection of Sprayed Fire-Resistive Materials Applied to Structural Members (E 759-80), Effect of Impact on Bonding of Sprayed Fire-Resistive Materials Applied to Structural Members (E 760-80), and Compressive Strength of Sprayed Fire-Resistive Materials Applied to Structural Members (E 761-80). ASTM Methods E 759-80 and E 760-80 are for a steel substrate. ASTM Methods E 736-80 and E 761-80 are for any rigid backing. Some considerations not directly related to thermal protection may be important in determining the practical feasibility of using coatings such as application temperatures, method of application, cure time, and water vapor transmission.

The small-scale tests did not involve an applied load on the specimens. Additional research is needed to determine performance of coatings on load-bearing assemblies. To obtain actual in-use performance, details of the total construction must be considered. Unprotected portions of the construction may lead to premature failure. The effect of joints in the membrane must be considered.

The development and use of fire resistive coatings in wood construction will depend upon their cost effectiveness. The economics of applying a coating versus increasing the member cross-sectional area may particularly limit the use of coatings on new products. Coatings are more likely to be an economical alternative when improving the fire resistance in existing buildings. It is hoped the fire resistance data reported in this paper will aid in future considerations of fire resistive coatings in wood construction.

Summary

Four fire retardant coatings and four fire resistive coatings applied to AC, Group 1 plywood were tested for fire resistance in a small vertical furnace using the ASTM E 119-82 time–temperature curve. The coated plywood was installed over a substrate of foam plastic. While a single coat of the fire retardant coatings only produced a minimum gain of 120 s, a gain of 920 s was achieved with multiple coats. With a 0.5-mm-thick flat, alkyd intumescent fire retardant coating, 16-mm (⅝-in.) plywood provided a 1580-s thermal barrier.

As expected, the fire resistive coatings provided more protection than the fire retardant coatings. A 6.4-mm ablative, epoxy intumescent mastic coating provided up to 2420-s improvement over uncoated plywood. With a 35-mm-thick mineral fiber coating on 16-mm (⅝-in.) plywood, a 3320-s thermal barrier (total time) was achieved.

The improvement in fire resistance provided by the coating depended upon the type and thickness of the coating and the thickness of the plywood.

Other performance characteristics and the cost effectiveness of coatings will need to be considered when evaluating possible applications in wood construction.

Acknowledgments

Avco Corporation, Carboline Company, Clark–Tectonics, Inc., Ocean Chemicals, Inc., and Stahl Industries, Inc., provided materials used in this study.

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DISCUSSION

F. G. Schway[1] (*written discussion*)—Can you characterize the fire resistive coating described as Contory H-epoxy? Is it a halogenated epoxy coating?

R. H. White (*author's response*)—Coating H is AVCO's Chartek 59. Chartek 59 coating is described as a filled amine-cured epoxy containing flame retardants. Its composition is considered to be proprietary information.

Neil Schultz[2] (*written discussion*)—What are the names of the manufacturers of the coatings for each type that was used in this project?

R. H. White (*author's response*)—The coatings are as follows:

A—Ocean Chemicals #320, Savannah, Ga.,
B—Ocean Chemicals #477,
C—Ocean Chemicals #777 and #776,
D—Ocean Chemicals #987,
E—Intumastic 285, Carboline, St. Louis, Mo.,
F—STAYTEX 4119A, Stahl Industries, Youngstown, Ohio,
G—Clark-Tectonics, Inc., Madison, Wis., and
H—Chartek 59, Avco, Lowell, Mass.

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[1] Coatings Research Group, Inc., Cleveland, Ohio.
[2] VTEC Laboratories, 540 Faile St., Bronx, N. Y. 01474.

Kathleen Bardell[1]

Spray-Applied Fire Resistive Coatings for Steel Building Columns

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REFERENCE: Bardell, K., "**Spray-Applied Fire Resistive Coatings for Steel Building Columns,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, *1983,* pp. 40–55.

ABSTRACT: This paper describes the insulative value of spray-applied, cementitious and mineral-fiber fire resistive coatings for steel building columns. It presents results of high-temperature thermal property tests of the materials used as input to a two-dimensional heat flow analysis designed for predicting the fire resistance of hollow steel columns. The prediction is compared with actual fire test data. The influence of the thermal properties of the materials and their application thickness on fire resistance is discussed.

KEY WORDS: steel columns, sprayed coatings, thermal conductivity, specific heat, heat transfer, numerical analysis, fire resistance

A principal aim of fire research is the prediction of the performance of structural assemblies in fire. To this end, the fire environment, the heat transfer process, and the response of the structure and its component materials must be understood and quantified. Until recently, information about the response of structural assemblies was gained solely through full-scale performance tests, usually in accordance with ASTM Standard Methods of Fire Tests of Building Construction and Materials (E 119-81), the Canadian Standard Methods of Fire Endurance Tests of Building Construction and Materials (ULC S101), or other comparable standards. Increasingly, however, techniques of heat flow and structural analyses, particularly numerical methods that permit the study of transient conditions, have been applied. Such methods permit prediction of the temperatures reached in assemblies during fires and their corresponding structural responses [*1,2*].

To use these techniques, the thermal and mechanical properties of the building materials that make up the structural assembly must be known. Prediction of material behavior at elevated temperatures is one of the weakest links in the analysis process, and the thermal performance of highly po-

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rous materials, such as spray-applied fire protection, is not well understood. This paper describes the results of a study of the influence of the thermal properties of fire resistive coating materials on the fire resistance of steel columns. Its focus was small diameter hollow columns sprayed with unusually thick coatings. The study was composed of thermal property tests, heat transfer analysis, and full-scale fire resistance tests.

Procedure

Materials

Two types of spray-applied coating were investigated, a cementitious mixture and a sprayed fiber (Underwriters' Laboratories Fire Resistance Directory designations CALV and CCAZ, respectively [*3*]). Nominal densities of both materials are in the range of 150 to 340 kg/m^3 (9 to 21 lb/ft^3).

Specimens were prepared for the thermal property tests by spraying both types of coating material on 2400-mm square plywood forms in 50 mm depth. The specimens were not conditioned but were at a moisture content in equilibrium with room temperature. The measured density of specimens of both materials was 311 kg/m^3 (19.4 lb/ft^3).

Spraying of the full-scale columns (steel, CSA G40.21M, 300 MPa, 2500 mm in height) was carried out by the coating manufacturers. The coated columns were then conditioned at room temperature for approximately five weeks. Densities of specimens obtained during spraying were calculated according to ASTM Tests for Thickness and Density of Sprayed Fire-Resistive Material Applied to Structural Members (E 605-77) and are shown in Table 1.

Thermal Property Tests

The thermal properties of solids of most importance in heat transfer analysis are thermal conductivity k and volumetric specific heat ρC_p, the product of density and specific heat [*4*]. The former reflects a material's ability to transmit heat; the latter is an indicator of its ability to store heat.

The transfer of heat through a porous material is a complex process of conduction through the solid phase and radiation and convection through the voids [*5*]. Unlike conduction, radiative heat transfer is roughly proportional to the fourth power of the temperature of the material and takes on increasing significance as temperature rises, for example, during fire exposure. Another factor that influences the apparent thermal conductivity of porous materials is moisture content. Whether water is chemically combined or present as free water in the pores, its endothermic dehydration or desorption tends to retard the flow of heat, particularly radiative heat transfer in the voids [*6*]. As the temperature of the material increases, this moisture may be driven out, and its movement may influence energy transport. At extremely high temperatures the chemical composition of the porous material may change, and mechanical instability or disintegration may occur. Thus, what

TABLE 1—*Column test program.*[a]

Test	Column	Protection Type	Protection Thickness, mm	Fire Resistance, min
1	round HSS, 141.3-mm OD 6.35-mm wall	cementitious, density = 293 kg/m^3	avg = 46 maximum = 53 minimum = 40	107
2	round HSS, 141.3-mm OD 6.35-mm wall	cementitious	avg = 64 maximum = 68 minimum = 58	157
3	round HSS, 141.3-mm OD 6.35-mm wall	sprayed fiber, density = 178 kg/m^3	avg = 43 maximum = 46 minimum = 38	106
4	round HSS, 141.3-mm OD 6.35-mm wall	sprayed fiber	avg = 62 maximum = 67 minimum = 61	136
5	square HSS, 101.4-mm^2 6.35-mm wall	cementitious	avg = 43 maximum = 46 minimum = 41	100
6	square HSS, 101.4-mm^2 6.35-mm wall	cementitious	avg = 63 maximum = 65 minimum = 61	166
7	square HSS, 101.4-mm^2 6.35-mm wall	sprayed fiber	avg = 43 maximum = 50 minimum = 40	101
8	square HSS, 101.4-mm^2 6.35-mm wall	sprayed fiber	avg = 64 maximum = 69 minimum = 60	140

is really measured in any test for thermal conductivity of a porous material is "effective" conductivity, which is a composite of all the previously mentioned effects. Clearly, it is important to measure this value over the range of temperatures likely to be encountered in fire environments, from room temperature to about 1000°C.

The specific heat of porous materials is greatly influenced by the presence of hydrated water and moisture [*4*]. As the temperature of the material reaches 100°C, the latent heat of vaporization (heat required to "boil away" moisture) is responsible for a large temporary increase in the apparent specific heat. Endothermic and exothermic chemical changes in the composition of the material at high temperatures (for example, dehydration) also contribute peaks and valleys, respectively, to the apparent specific heat.

Techniques for measuring the thermal properties of porous fire protection materials are aimed at ascertaining any variation in properties with temperature. Harmathy [*7*] has developed a technique and apparatus for the measurement of thermal conductivity over a range of temperatures (Fig. 1). The apparatus includes a furnace inside which the 75- by 150-mm 12-mm-thick specimen is placed. Once the target furnace temperature has been reached a constant current is introduced into a conducting foil placed on one face of a slab-like specimen embedded in a larger block of the same material. Ther-

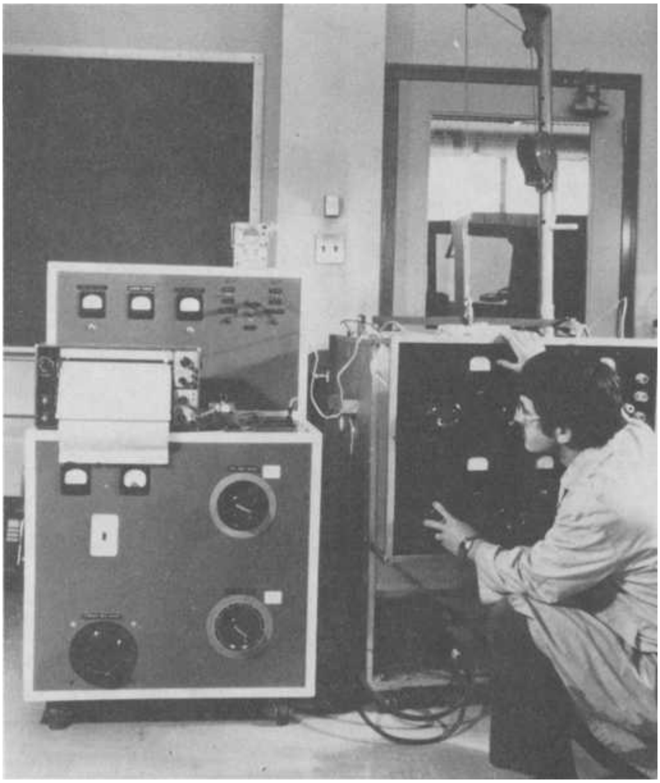

FIG. 1—*Thermal conductivity test apparatus.*

mocouples record the temperature rise over a 420-s period on the other face. Thermal conductivity of the material is calculated from the temperature rise. Specific heat can be measured over a range of temperatures by a scanning calorimeter; a Dupont 910 Differential Scanning Calorimeter was used for this study (Fig. 2). The scanning rate is usually 5°C/min, and a continuous plot is obtained from which the c_p versus temperature relation is evaluated; 10- to 30-mg specimens are normally used. More information on the thermal property measurement techniques can be found in Ref *7*.

Thermal Analysis

The standard fire resistance test, ASTM E 119-81, exposes an assembly to a fire of controlled severity defined by a standard time-temperature curve. The fire resistance of a protected structural steel column may be defined as the test time at which the steel reaches an average temperature of 538°C. Thus, by this definition, structural fire resistance may be predicted by thermal analysis alone. In reality, the fire resistance of steel columns is also a function of gravity load and end restraint [*8*].

FIG. 2—*Calorimeter.*

Lie and Harmathy [1] have developed a two-dimensional numerical heat flow analysis technique for predicting the temperature a protected steel column will reach during a simulated standard fire test. This computerized finite difference method makes the following assumptions about heat transfer mechanisms:

(1) heat transfer from fire to column is radiative,
(2) heat transmission through protection material is conductive,
(3) thermal resistance between protection and steel is negligible, and
(4) steel temperature is uniform over the cross section.

Thermal properties of the protection materials, which vary with temperature, and the geometry of the steel section are required input for the analysis. Temperature histories of hollow steel columns protected with both types of spray-applied coating were analysed by this technique.

Full-Scale Fire Resistance Tests

The thermal analysis results were verified by full-scale fire resistance tests on unloaded hollow structural steel columns protected with the coatings (Fig. 3). Table 1 lists column sizes and coating thicknesses for tests carried out according to ASTM E 119-81, four at a time, in the column furnace of the laboratories of the National Research Council of Canada. Furnace temperature was controlled by nine symmetrically placed furnace thermocouples to follow the standard time-temperature curve. The steel columns were insu-

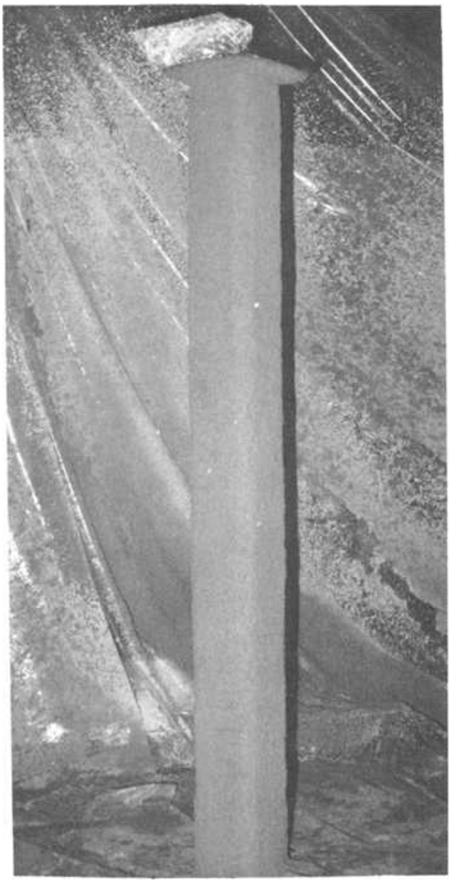

FIG. 3—*Full-scale coated column.*

lated at the top and bottom with ceramic blankets to prevent vertical heat loss. Steel temperatures were measured by thermocouples peened to the surfaces of the columns at four symmetrical points on the circumference at each of three levels spaced 600 mm apart over the height. Tests were terminated when the average temperature of the steel in all columns reached 600°C.

Results and Discussion

Thermal Property Tests

Figure 4 shows the results of thermal conductivity measurements for the two fire protection materials. Values range from 0.06 W/m°C at room temperature to 0.19 W/m°C at 700°C. A peak in the thermal conductivity versus temperature curves at 100°C probably indicates moisture in the materials. Figure 5 shows the calorimeter test results. Values range from 800

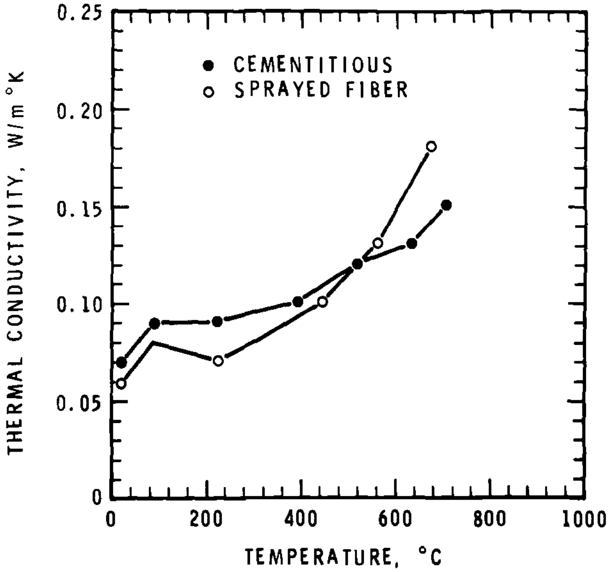

FIG. 4—*Thermal conductivity.*

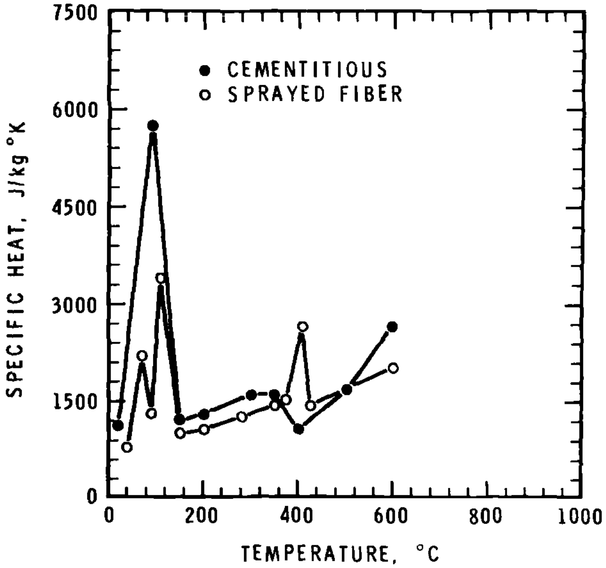

FIG. 5—*Specific heat.*

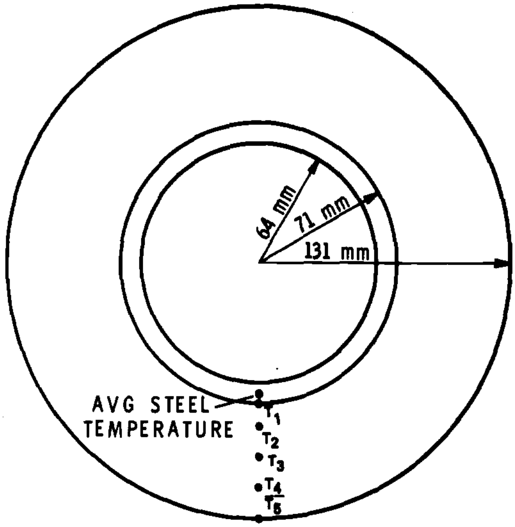

FIG. 6—*Typical column cross section.*

J/Kg°C at room temperature to 2600 J/Kg°C at 600°C. The large peaks at 100°C show the heat required to vaporize moisture in the material. The peak and valley at about 400°C probably represent chemical changes in the materials, involving absorption and evolution of heat, respectively. It is apparent that the thermal conductivity and specific heat of both fire protection materials are similar in magnitude and temperature variation.

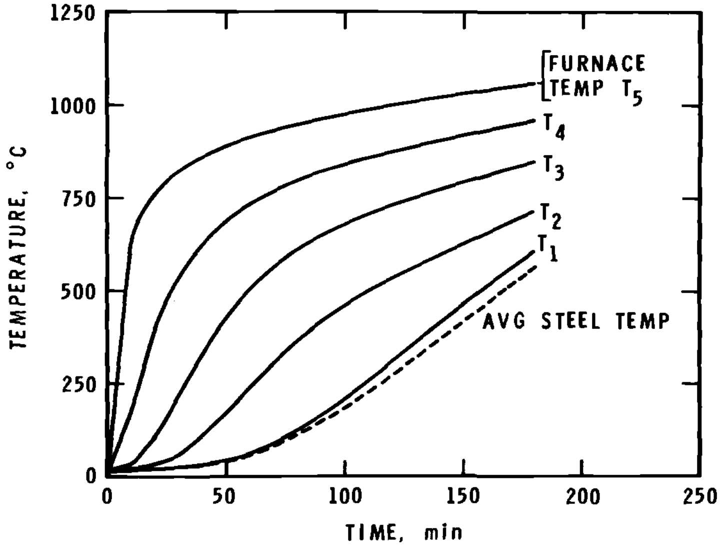

FIG. 7—*Insulation temperature profiles—sprayed-fiber protection.*

Thermal Analysis

Figure 6 shows a typical column cross section, and the locations at which temperatures were calculated. The thermal conductivities of the spray-applied materials measured in the thermal property tests (Fig. 4) were used as input to the analyses. The curves were extrapolated beyond 600°C as required. Since variation of specific heat with temperature generally has less influence on steel temperature [*4*], a constant specific heat value corresponding to that measured at 500°C in the small-scale tests was used for the analyses.

Figures 7 and 8 are plots of predicted temperatures versus time of exposure for columns (Fig. 6) protected by the two materials. The plots illustrate the steep thermal gradients to which the fire protection materials were exposed. As might be predicted from Figs. 4 and 5, the two protection materials behaved similarly.

Figure 9 indicates the relation between steel temperature and the thermal conductivity of the protection material. The steel temperature of the column in Fig. 6 was predicted using double and then half the experimental values of thermal conductivity of the cementitious material as input to the thermal analyses. For comparison, analysis was also carried out using a constant thermal conductivity value equal to that at room temperature. It is apparent that the steel temperature is very sensitive to the thermal conductivity of the protection materials.

Figure 10 shows a similar study of the influence of the specific heat of the protection material on steel temperatures. Values of double and then half the 500°C measured specific heat of 500 kJ/m^3°C were used as input.

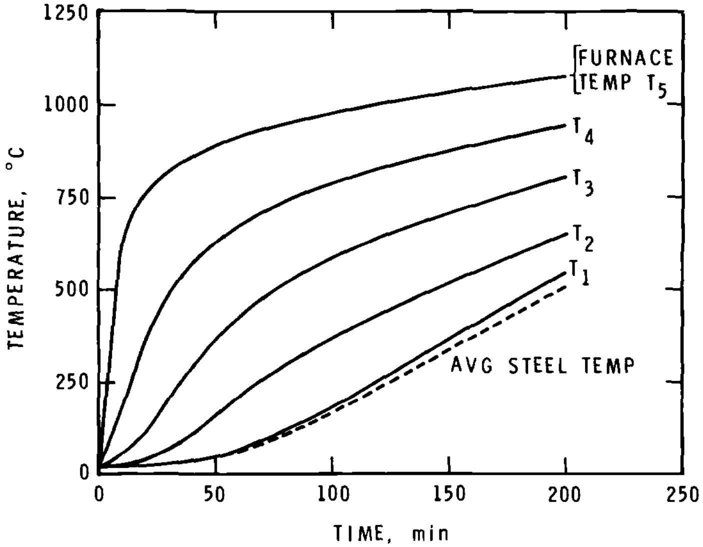

FIG. 8—*Insulation temperature profiles—cementitious protection.*

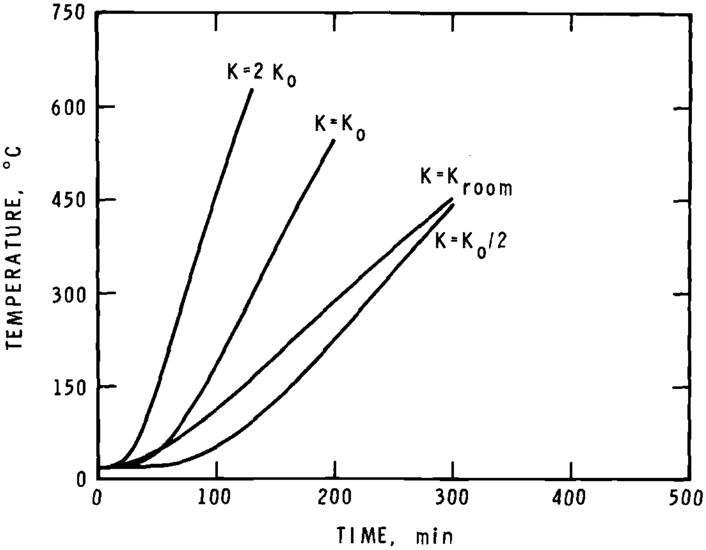

FIG. 9—*Influence of protection thermal conductivity on steel temperatures.*

Figure 11 shows the predicted influence of protection thickness on fire resistance (time in minutes to reach a steel temperature of 538°C). Heat transfer analyses of fire tests on columns (Fig. 6) protected with 20 to 100 mm of each of the protection materials were carried out. For this particular column the relation between protection thickness and fire resistance appears to be linear, with a slope of approximately three.

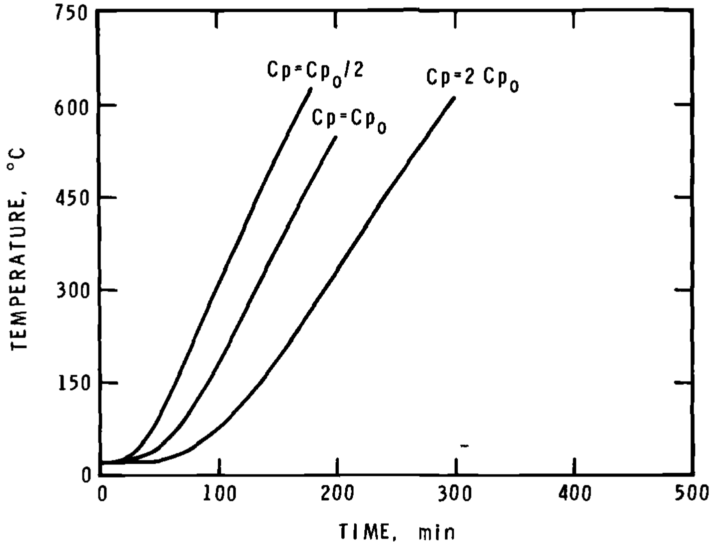

FIG. 10—*Influence of protection specific heat on steel temperatures.*

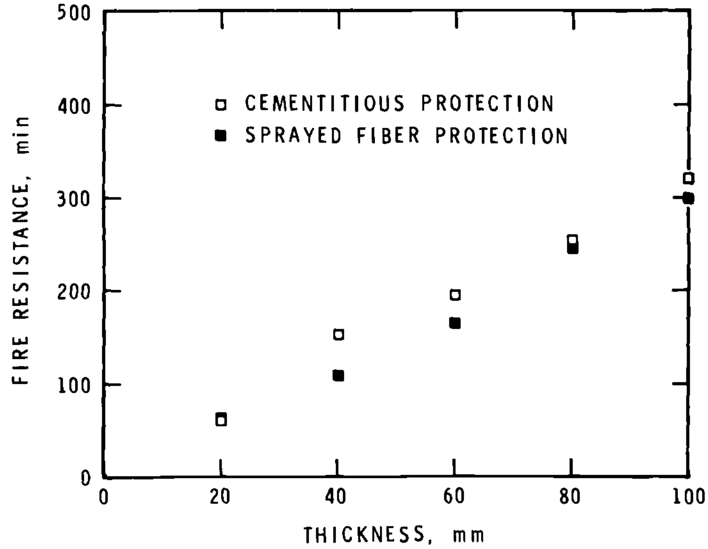

FIG. 11—*Influence of protection thickness on fire resistance.*

Fire Resistance Tests

The duration of the full-scale fire resistance tests was 2 and 3 h for columns coated with 40 and 60 mm, respectively, of protection material. Table 1 lists the fire resistance values (time to an average of 538°C at any level). Both materials remained stable during the tests and there was no spalling.

Figures 12 and 13 show the experimental change in steel temperature with

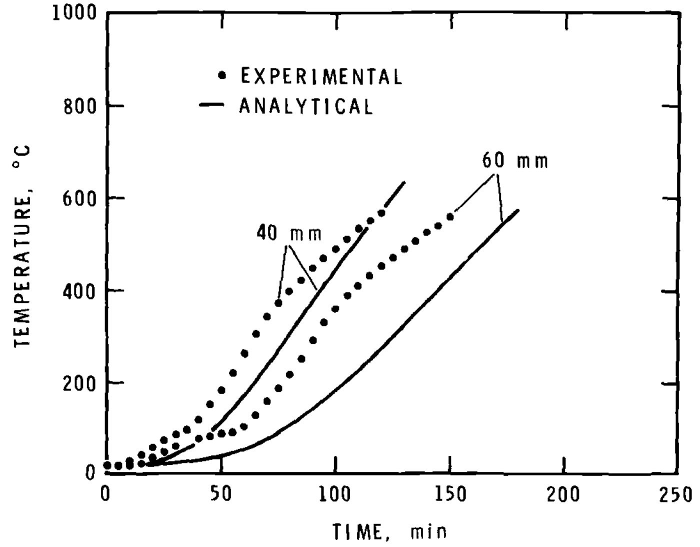

FIG. 12—*Experimental steel temperatures—sprayed fiber protection.*

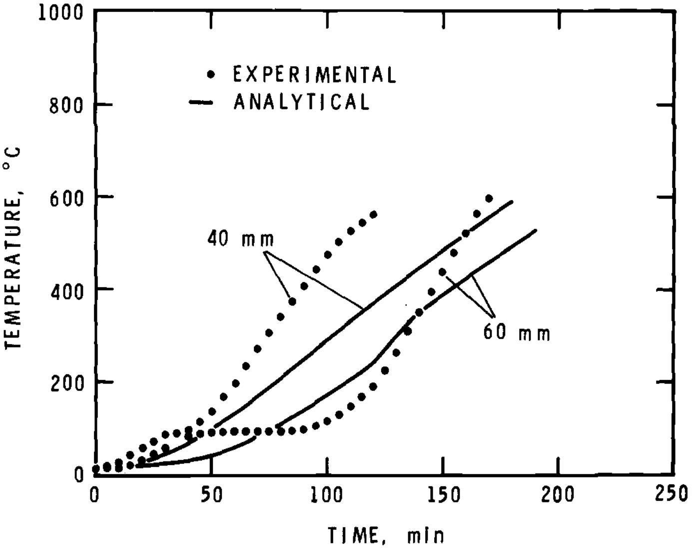

FIG. 13—*Experimental steel temperatures—cementitious protection.*

time compared with that predicted by thermal analysis. Test steel temperatures are substantially higher in certain temperature ranges than those predicted by analysis based on thermal conductivity and specific heat values obtained in the thermal property tests. There appear to be two reasons for this discrepancy. First, as may be seen in Fig. 13, the column coated with cementitious material, particularly that with a 60 mm thickness, contained free and hydrated water; evaporation kept steel temperatures on a plateau of approxi-

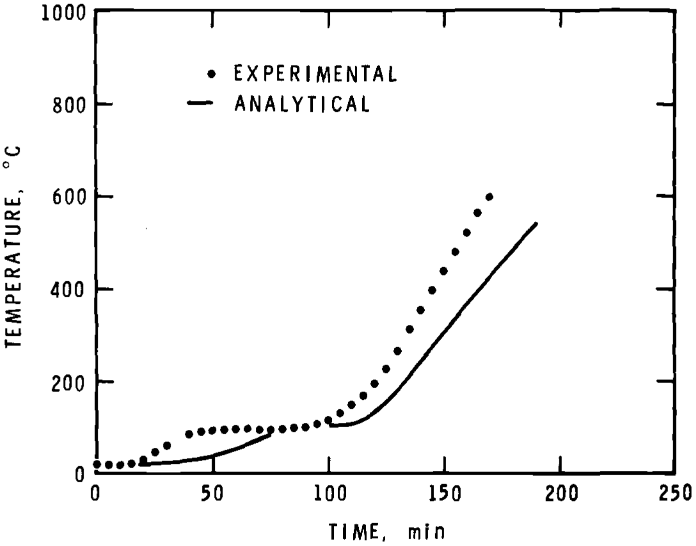

FIG. 14—*Influence of moisture on steel temperatures.*

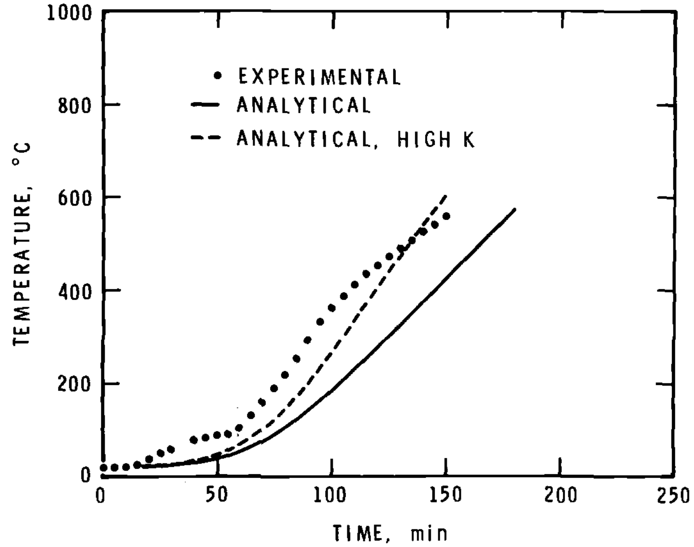

FIG. 15—*Influence of thermal conductivity above 600°C* on steel temperature.

mately 95°C for 45 min. A shorter plateau may be observed in Fig. 12 as well, representing the results for sprayed-fiber coated columns. It appears that a conditioning period of five weeks may be insufficient to dry this thickness of material. Figure 14 shows the thermal analysis of columns (Fig. 6) protected with cementitious material, repeated with the presence of moisture taken into account. (A higher thermal conductivity value was also used, as explained below.) The same plateau occurs in the analysis results.

The second cause of deviation in experimental fire resistance from theory is a fundamental problem in the technique used for measuring thermal conductivity: measurements can only be made up to about 600°C. Figure 7 indicates that most of the protection material was at temperatures above this value for the greater part of the fire resistance period. Thus, thermal analysis is largely based on conjectured values of thermal conductivity derived from extrapolation of lower temperature results. As previously mentioned, radiative heat transfer is of increasing significance at high temperatures so that a linear extrapolation may not be appropriate. Figure 15 shows the results of thermal analysis of the column (Fig. 6) protected with sprayed fiber where the slope of the thermal conductivity versus temperature curve is doubled above 600°C. The influence on steel temperatures is extremely significant.

Conclusions

The thermal properties of spray-applied fire protection materials are essential pieces of information in predicting the fire behavior of steel columns. Thermal analysis demonstrates that column fire resistance is very sensitive to protection thermal conductivity.

Acknowledgments

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DISCUSSION

Recorded Discussion

Morris Lieff[1]—The specimens that were used as drying controls, how large were they?

Kathy Bardell—About 77 cm^2 (12 in.^2) and about 51 mm (2 in.) deep.

Morris Lieff—Perhaps you get an edge effect in the drying of these small specimens, particularly in the thick ones. Perhaps if specimens were larger and you sealed the edges.

Kathy Bardell—The drying control specimens were sprayed into a flat plywood form. Horizontal specimens dry more quickly and thus they were probably much drier than the column's coating. I think if we had anticipated the problem we would probably have used more sophisticated humidity monitoring devices such as moisture probes.

Bob Berhinig[2]—Do you have plans on rerunning any of these tests?

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[1] County College of Morris, Dover, N. J. 07869.

[2] Underwriters Laboratories, Northbrook, Ill. 60062.

Kathy Bardell—No, we don't at the moment. We weren't that concerned with the actual fire resistance number itself. We were more interested in predicting what was happening with predicting behavior using thermal analysis and as I showed you, once we knew about moisture, we were able to do this.

Bob Berhinig—Are there probes available for measuring the moisture content?

Kathy Bardell—Available? Yes. That's right.

Bob Berhinig—Another question is on the computer program, FIRES-T3. Was there an attempt made to input the thermal conductivity and specific heat values?

Kathy Bardell—FIRES-T3 is a general three dimensional heat transfer analysis program with which one can analyse any shape and size of specimen including three dimensional heat flow. The program that I refer to is one developed by Drs. Lie and Harmathy from the National Research Council (NRC), which was developed specifically to analyse heat flow to columns. It handles two dimensional heat flow, and the input is the column geometry and the protection thicknesses. So it's much easier to use than a general heat transfer three dimensional program, but it's designed exactly on the same basis. There's more detail regarding the assumptions in the program in the written paper.

Manny Herrera[3]—What was the percent moisture for the fiber and the percent moisture for the cementitious specimens at constant weight, and how long did it take for each of them to reach constant weight?

Kathy Bardell—It took about three weeks for the small specimens to reach constant weight. We waited five weeks to test the columns, that is, five weeks at room temperature in Ottawa in a cold wet August.

Morris Lieff—When those tests are run, for example, at the Underwriter's Laboratory (UL), they are on metal plates so you don't get any drying out of the back. You're only getting drying from the face, which would be comparable to the columns. You had much more area exposed in your specimens.

Kathy Bardell—Yes, the columns were free standing in the lab. At five weeks the moisture content was 21 and 10%. These figures include some hydrated water for the cementitious and mineral fiber insulation, respectively.

Jack Campbell[4]—Practically speaking, both the fibrous and cementitious protection show approximately equal to resistance value.

Kathy Bardell—That's right.

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[3] American Energy Products Corp., Pico Rivera, Calif. 90660.

[4] Conrail.

Jack Campbell—Can you conclude from our user standpoint, which withstood the heat better from abrasion, disintegration or falling off the actual structural steel column that is under protection after a prolonged period. Did you come to any conclusion as to which could stand the physical abuse better?

Kathy Bardell—I wouldn't say that there would be much difference between the two. We didn't have any problems with abrasion, with any handling problems at all.

Jack Campbell—If taken to destruction, which do you think would fall off the column first?

Kathy Bardell—Well, neither of them fell off so I can't really say, not on the basis of these tests. Both of them were intact after the 3-h test.

Frank Stumpf[5]—Kathy, is there a difference between the column weights, and how close do they come to the specification requirements.

Kathy Bardell—Steel column weights?

Frank Stumpf—The mass of the steel columns, yes.

Kathy Bardell—There were two shapes tested. We didn't weigh individual columns. The two shapes were 26 cm^2 (4 $in.^2$), and 6.35 mm (5½ in., round, both ¼-in.) wall. The W/D value, the ratio of the weight to perimeter of the columns was very similar. So we would have expected similar fire resistance values for the round and the square.

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[5] United States Mineral Products Company, Stanhope, N. J. 07874.

Neil Schultz[1]

Evaluation of Fire Resistive Coatings Based on Small-Scale Fire Testing

REFERENCE: Schultz, N., **"Evaluation of Fire Resistive Coatings Based on Small-Scale Fire Testing,"** *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 56–67.

ABSTRACT: Economics and short-time factors have forced many manufacturers of fire resistive coatings to use small-scale fire tests in accordance with ASTM Standard Method of Fire Tests of Building Construction and Materials (E 119-81) time-temperature curve. The difference between small-size and full-size furnaces is not so much in the geometry as it is in the construction. Insulation, burners, and fuel type are influencing factors when making a comparative analysis. The American Iron and Steel Institute (AISI) used a full-size column furnace and a small-column furnace in one of their programs. The correlation between data was substantial enough to focus the attention on using the small furnace as a valid means of testing.

Within the same scenario of small-scale testing, a high intensity fire test (HIFT) is established to simulate a petroleum spill fire. It is being used by the petrochemical industry and fire resistive coating manufacturers to evaluate materials under reproducible simulated thermal conditions of a petrochemical fire.

KEY WORDS: fire resistive coatings, small scale, fire testing, furnace construction, heat flux, loading high intensity fire tests (HIFT), petroleum spill fire

Where building codes require fire protection designs for steel columns, such designs are based on fire tests specified by ASTM Standard Method of Fire Tests of Building Construction and Materials (E 119-81). These test procedures evaluate the ability of structural members or assemblies to withstand a standard fire exposure while entirely confined in a test chamber. Although the design of this test chamber (or furnace) is unspecified, the length of the column to be tested is specified as 2.44 m (8 ft).

The limiting temperature of a steel column, as defined by ASTM E 119-81, occurs when the average temperature on a cross section reaches 538°C (1000°F) or when the temperature reaches 649°C (1200°F) whichever occurs first.

An ever increasing variety of sizes and shapes of steel is being used by the construction industry, and the expense of conducting "full-scale" ASTM

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[1] Executive director, VTEC Laboratories, Inc., Bronx, N. Y. 10474.

E 119-81 fire tests on all of these configurations is rapidly becoming prohibitive. Especially when the additional factor of a multiplicity of coating thicknesses is considered for each of these steel sections.

Another indirect deterrent to large-scale testing is the time factor. Many vendors are operating on tight schedules where testing is required for a particular job, which does not allow much time for test work. Most large-scale testing requires months of filling out numerous forms before the project is even started. Many of the large-scale fire testing laboratories will not schedule testing until the specimen is received. This can invariably cause further delay and frustration on the part of the vendor.

Significant cost savings could be realized if many of these new structural members could be tested for fire resistance on a small-scale basis. Furthermore, even greater savings would result if mathematical calculations could be used to determine the fire resistance for a large number of structural shapes with only a reduced number of actual fire tests being conducted.

There are numerous small-size furnaces that can test structural sections. These small-scale furnaces are owned by vendors and an independent testing laboratory in the United States. A small furnace will be defined as one that can perform ASTM E 119-81 testing on any structural shape with a minimum of 0.914 m (3 ft) in height.

As a step in this direction, the American Iron and Steel Institute (AISI) has sponsored a number of projects to determine the feasibility of using a combination of full-scale, small-scale and calculations to reduce the overall cost of fire testing.

Most of the small-scale tests sponsored by AISI were conducted at Smithers Scientific Services (SSS). The furnace used in these tests has been acquired by VTEC Laboratories and is now installed and operating in the Bronx, N. Y.

In this paper, I will discuss the small-scale test results achieved in the AISI programs as well as additional small-scale tests conducted to simulate the conditions of high intensity hydrocarbon spill fires.

Characteristics of Test Furnaces

There are over a dozen furnaces in the United States that can test in accordance with ASTM E 119-81. There are only three or four that can test full-size columns. The construction varies between furnaces, but they are all capable of following the ASTM E 119-81 time-temperature curve.

The difference in construction ranges from types of burners to insulation. The outside shell of almost all furnaces is steel plate, usually painted with a high-temperature paint on the unexposed surface.

The insulation varies from fire brick to ceramic fiber linings. The type of insulation used could greatly effect the heat profile in the furnace. A brick will not reradiate into the furnace at the same rate as a refractory liner. This is also true of absorption. The emissivities of refractory material range from 0.22 to 0.85, and conductivities range from 21.6 to 96.5 W/m^2 °C (3.8 to 17

Btu in./h ft^2 °F) at 1093°C (2000°F). To compensate for these differences, the burners are adjusted to supply more or less heat as needed. Currently there is no heat flux requirement for the ASTM E 119-81 test, so the choice of lining is determined by other criteria, such as cost, maintenance, and furnace life.

The burners are another variable that add to the complexity of an otherwise simple furnace. The basic designs vary from premix or diffusion type systems. The basic function of the burner is to deliver fuel and air to the combustion space, to mix the air and fuel, and to assure a continuous burning flame at various efficiency ratios. The flame can either be a long luminous type or a flat flame nonimpinging design. Each type of flame has its own physical characteristics. Some more important ones include convection, thermal conduction, and molecular diffusion heat transfer characteristics. The heat output in Btu/h differs, but once again regulation of the fuel-air mixture can compensate for deviations from the desired temperature. However, this will vary components of the heat flux.

With different burners come various fuel types. Test standards do not indicate this variable, so any fuel type is acceptable. If practical, even electric resistance elements would be acceptable. It appears that most furnaces use natural gas, with a few using propane or oil. The heating values of these fuels range from 3.84×10^7 J/m^3 (1030 Btu/ft^3) for natural gas to 1.26×10^8 J/m^3 (3370 Btu/ft^3) for normal butane. With different heating values, there are also various heat fluxes, flame temperatures, and burning characteristics. These parameters are also partly controlled by the burner type.

The flame has its own signature, which is characterized by the tube of burner and fuel. The different heat fluxes produced by these flames will vary in radiative and convective components. During the oxidation of the fuel, a rapid rise in temperature is experienced because of the inability of the transport processes (conduction, convection, and radiation) to transfer heat to the surroundings as rapidly as it is produced by the oxidation reaction. Therefore, the flame type can change yielding different heat fluxes. Some furnaces use a "lazy" luminous flame, while others use a "flat" flame. These flames would give different heat fluxes while still maintaining the same temperature.

The nature of the inside surface of the furnace affects convection heat transfer to a small degree depending upon its roughness. However, the radiation from the surface is dependent upon the emissivity (ability to radiate) and absorptivity (ability to absorb radiation).

Dark surfaces are very good emitters and absorbers, which is typical of many brick furnaces, while a smooth shiny surface is a poor emitter and absorber of radiation, which is more typical of a refractory insulation lined furnace. The total emissive power is the total radiant energy emitted per unit time per unit area of radiating surface.

$$E = \sum_{\lambda=0}^{\lambda=\infty} E\lambda d\lambda \tag{1}$$

where

E = total emissive power of a body,
$E\lambda$ = monochromatic emissive power (radiant energy emitted by the body at a particular temperature and wavelength), and
λ = wavelength.

It has been shown that E for any particular temperature is the area under the energy distribution curve for that temperature. The energy radiated by a body at a given temperature varies with wavelength. The relationship between energy radiated and wavelength is called the energy distribution curve for that temperature. The emissivity is not based on total area but the E of the furnace and the wavelength. At different temperatures, the emissivity and wavelength change.

There is also a relationship between the total emissive power E of any body at a given temperature and its absorptivity a at the same temperature

$$E_1 = Ia_1 \tag{2}$$

where I is the radiation falling on the body per unit time and per unit area. Other relationships involving radiation such as Kirchloff's law, Stefan-Boltzmann's law, and Planck's formula do not directly relate to size. They use temperature, wavelength, emissivity, and absorption to establish proven relationships.

Other methods used for designing fire test furnaces include heat balance equations. The design can be based on calculated heat loss to the surroundings at maximum operating temperature under steady state conditions. Fire test furnaces operate under variable state conditions, a result of their time-temperature curves. The heat balance or principle of conservation of energy is the initial basis for the design. Actual physical sizes are not major criteria. All calculations are based on heat flow per unit area [*1*].

A number of furnace designs have been used in testing structural materials and fire protective coatings according to ASTM E 119-81. The characteristics of some of these furnaces are summarized in Table 1.

TABLE 1—*Heat flux characteristics of selected furnaces.*

Furnace	Temperature	Total Heat Flux, W/m^2	Radiant Heat Flux, W/m^2	Convective Heat Flux, W/m^2
UL column furnace	927°C	117 217	92 088	25 129
ASTM E 119 (at 1 h)	1700°F	37 168 Btu/ft^2 h	29 200 Btu/ft^2 h	7968 Btu/ft^2 h
NRC floor furnace	927°C	175 819	133 969	41 849
ASTM E 119 (at 1 h)	1700°F	55 750 Btu/ft^2 h	42 480 Btu/ft^2 h	13 270 Btu/ft^2 h
VTEC furnace	927°C	173 488	167 146	6342
ASTM E 119 (at 1 h)	1700°F	55 011 Btu/ft^2 h	53 000 Btu/ft^2 h	2011 Btu/ft^2 h

The VTEC furnace uses natural gas premixed with air, both under pressure. This results in a different flame configuration from that of the National Research Council (NRC) burners, and a higher radiative component.

The subject furnace used for the small-scale testing was 1.52 by 1.52 by 2.13 m (5 by 5 by 7 ft) in height. It is designed with four burners, one centered on each wall to provide uniform heat. Each burner is rated for 439 650 W/h (1.5 million Btu/h) and is of the flat flame or nonimpinging flame design. The furnace is lined with a high-temperature refractory insulation. Furnace conditions are monitored by four Inconel®-sheathed thermocouples placed 0.203 m (8 in.) from the face of the specimen. Specimens are loaded from the top and positioned so as to be an equal distance from the burner. High-temperature insulation is placed around the base of the column to prevent heat loss at these points.

On the basis of measured values for the Underwriters Laboratories (UL) and the NRC furnaces under ASTM E 119-81 conditions, one would expect the NRC furnace to be more severe. The UL furnace is fired by low-pressure natural gas entering through annuli around the pipes. The flame is lazy and characteristic of low-velocity diffusion mixing. The NRC furnace is fueled with propane premixed with air by aspirating burners. The premixing of propane and air results in a higher flame temperature, thus higher radiative component than the UL furnace although still lower than the VTEC furnace.

AISI Comparative Analysis

Published test data that permit a direct comparison between furnaces are scarce. However, in a program sponsored by the AISI, a series of tests were conducted on a low-density magnesium oxychloride coating. Three W10X49 columns 0.914 m (3 ft) had been previously coated and tested with the same material 0.032 m (1¼ in.) at the UL.

Two of the 0.914-m (3-ft) columns were tested at NRC (in two separate tests), and the remaining 0.914-m (3-ft) column was tested at SSS. The standard ASTM E 119-81 time-temperature curve was followed on all three tests. The results of these limited comparisons were extremely close, considering the differences in specimen size and furnace conditions (Table 2).

TABLE 2—*Times for various furnaces to reach 1000°F.*[a]

Test Furnace	Time Needed to Reach 1000°F, min
UL	135
NRC	135
NRC	144
VTEC (SSS)	143

[a] 1000°F = 538°C.

TABLE 3—*Comparison of fine endurance of similarly protected specimens tested at VTEC and at UL.*

Specimens	Coating, m (in.)	VTEC, min	UL, min
Specimen A			
W10X49	0.032 (1¼)	120 (126)	122
W6X16	0.038 (1½)	100 (104)	116
Specimen B			
W10X49	0.032 (1¼)	114	
	0.032 (1¼)	115	
	0.038 (1½)	145	163[a]
W6X16	0.030 (1½)	98	112
	0.038 (1½)	98	
W8X28	0.035 (1⅜)	112	121

[a] Estimated by UL to be 144 min.

In view of these results, the AISI sponsored an additional series of 41 fire tests on 9 different column shapes and sizes.

Several of the test assemblies were chosen to be identical in size and shapes to assemblies previously tested at UL. The purpose of this study was to compare heat transfer information derived from tests of full-size columns when tested in accordance with ASTM E 119-81 7.44 m (8 ft), with the results from the small fire test furnace and 0.914 m (3 ft) high columns.

Only limited data were available for direct comparison with UL data; the results are tabulated in Table 3. Bear in mind that the reproducibility of the thermal fire endurance is about ±4% for full-size columns.[2]

The W10X49 small-scale tests correlate very closely with the full-size tests.

Lighter columns reach their end points more rapidly in small-scale testing than in large-scale testing when the data are examined. However, results are within the tolerances between large-scale fire tests. The maximum difference between the small-scale and full-size tests is 3.3%.

Test results for the remaining 0.914-m (3-ft) sections in the AISI program are tabulated in Table 4. The fire endurance time as predicted by the equation developed by Harmathy and Lie [*2*] is also tabulated in Table 4.

Loading of Specimen During Fire Test

There is still a lack of complete understanding as to what causes crack formation and collapse of protection materials in fire. Ideally the specimen size tested should be comparable to that used in construction. This is not always practical. To meet this end, it has been ascertained through experimental evidence that the primary mode of failure for a specimen is by heat transfer through the protection. In such a case, there is no need to insist on

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[2] *Division of Building Research/National Research Council of Canada.*

TABLE 4—*Comparison of predicted and actual fire endurance in AISI program.*

Structural Shape Designation	Fire Protection Thickness, m (in.)	Fire Endurance Time, min	
		Predicted	Test
TS4 × 4 × $^{3}/_{16}$	0.044 (1.75)	125	108
W6 × 16	0.038 (1.50)	105	98
TS4 × 4 × $^{3}/_{16}$	0.044 (1.75)	125	104
W4 × 13	0.048 (1.88)	129	177
TS4 × 4 × $^{3}/_{16}$	0.048 (1.88)	134	165
W4 × 13	0.048 (1.88)	129	183
Two 2 × 1½ angles with long legs back to back	0.064 (2.50)	173	166
Two 2 × 1½ angles with long legs back to back	0.064 (2.50)	173	167
Two 2 × 1½ angles with long legs back to back	0.069 (2.75)	190	176
Light gage steel C-shape	0.038 (1.50)	59	58
Light gage steel C-shape	0.064 (2.50)	98	145
W8 × 28	0.035 (1.38)	107	112
4 in. standard pipe[a]	0.019 (0.75)	63	64
4 in. standard pipe	0.044 (1.75)	146	116
4 × 6 pre-engineered material building column	0.032 (1.25)	61	62
4 × 6 pre-engineered material building column	0.032 (2.25)	110	134

[a] 1 in. = 25.4 m.

testing full-size loaded specimens, and the heat transmission problem can be studied more conveniently on specimens of a much smaller size [*2*].

The criterion for failure of loaded specimens subjected to a fire environment is usually mechanical failure (that is, yielding as buckling of the steel) under the applied load. Since it is difficult in practice to subject a specimen simultaneously to load and fire environment, specimens are often tested in the unloaded mode, with steel temperature arbitrarily used as failure criteria. A temperature of 538°C (1000°F) is traditionally chosen as the failure temperature because steel loses approximately half of its tensile strength at that temperature.

Fire testing in the unloaded mode can be reliably scaled down to 0.92-m (3-ft) column specimens because failure is caused by thermal considerations only. Simply stated, the specimen fails when the average steel temperature reaches 538°C (1000°F).

Fire testing in the loaded mode cannot be scaled down reliably, since mechanical failure not only depends on the steel temperature, but also on specimen size. For example, a loaded column will fail by buckling, and critical buckling load is strongly dependent on specimen length. When speaking of specimens of reduced size, it is not implied that the dimension in the direction of the principal heat flow be scaled down [*3*].

In cases where protection stress-deformation is a deciding factor, the problem can be broken into two parts, stress deformation and heat transfer, each independent of the other. In some cases the stress deformation problem can be solved from data obtained from the heat transfer information. With current knowledge, it is becoming more relevant to test small scale for fire endurance. This trend will continue in light of prevailing economic constraints and development of a understanding of the nature of fires in structures.

Small-Scale Testing for Petroleum Spill Fires

The ASTM E 119-81 curve is considered meaningful for ordinary buildings, and brick and wood structures containing normal combustibles, but it is not applicable to hydrocarbon spill fires and the open construction common to the chemical process industries.

Waldman [*3*] pointed up that fire loadings for chemical plants can run much higher than those for ordinary factory or warehouse installations. The flame temperature of burning liquids in a petrochemical plant or a refinery can theoretically approach 2204°C (4000°F) although actual flame temperatures are much lower.

Oil and petrochemical companies are demanding a more severe fire test than ASTM E 119-81, but at this time there is still no standardized test. In the absence of a standard test at more severe conditions, there has been a proliferation of pit- and pool-fire tests conducted, many so poorly designed as to be meaningless when used for comparing fire-protective products.

A rough representation of actual conditions in an open structure petrochemical fire has been obtained with pool- and pit-fire tests. The first technique involves simply igniting a pool of hydrocarbon fuel having a measured diameter and then measuring flame properties. It is difficult to control experimental conditions in pool fires, since they are strongly influenced by wind effects. Also, one specimen may be fully enveloped in a flame, whereas the other, upwind, may be exposed for a shorter, less representative period of time.

The second type of open-flame test is the pit fire, used whenever highly volatile fuels are likely to be present. The pit fire is essentially a pool fire whose perimeter is enclosed by walls; the walls heat up rapidly, but obstruct most of the radiative heat loss from the combustion gases. The walls also reduce wind effects. Flame conditions, which may vary somewhat with air and fuel distribution, generally result in gas temperatures and heat fluxes that are more uniform over the test volume than for comparable pool fires.

Much has been written about pool fires and pool-fire environments. More recently, the emphasis has shifted from merely attempting to determine the temperature of these fires to measuring heat flux, total, radiative, and convective. This has not been a simple task. However, in recent years the temperatures of a number of relatively large fires have been accurately mea-

TABLE 5—*Characteristics of several pool- and pit-fires* [*4*].

Environment	Temperature, °C (°F)	Total Heat Flux, W/m² (Btu/ft² h)	Radiant Heat Flux, W/m² (Btu/ft² h)	Convective Heat Flux, W/m²
Propane pit fire (7 ft × 3 ft)[a] 2.13 m × 1.56 m	1204 (2200)	(71 640)	91 962 (29 160)	(42 480)
Naval Ordinance Lab Pool fire[a]	1093 (2000)	225 931	163 267 (51 770)	133 969
AVCO-NASA pool fire, using JP-4 (10 ft dia.)[a] 3.05 m	977 (1790)	159 073 (50 440)	...	...
DOT-NASA pool fire using JP-4 (80 ft × 30 ft) 24.38 m × 9.14 m	1087 (1990)	138 148 (43 805)	46 927 (14 880)	91 221 (28 925)
DOT-NASA propane torch (73 lb/s) 33.1 Agls	1093 (2000)	...	159 073 (50 440)	...

[a] On the subject of high intensity fires there is still no standard test, even after many years of ASTM committee studies.

sured, and, in some cases, reliable heat-flux measurements have been obtained.

Examples of some of these fires and their thermal properties are listed in Table 5. These measurements tend to confirm maximum temperature ranges of 982 to 1093°C (1800 to 2000°F) for typical chemical-plant pool fires. Unfortunately, the heat-flux levels were not always adequately measured in terms of total heat flux and the radiative and convective components.

One way to avoid the environmental variations inherent in field pool-fires or pit-fires is to devise a furnace test based on a standard heating procedure.

In 1975, a series of high intensity fire tests (HIFT) were conducted in the VTEC (SSS) furnace, using 0.914-m (3-ft) columns. A time-temperature curve that reaches 1093°C (2000°F) within 5 min and holds that temperature for the duration of the test, was selected because this curve falls at the upper level of the range of temperatures normally encountered in spill fires.

There are furnaces throughout the continental United States that can test as per the previously designated specification for a HIFT. These facilities are owned by manufacturing concerns and independent laboratories. Testing by this method is practical, currently available, and cost effective. To date, there is only one independent testing facility in North America that can perform the HIFT on a small-scale column [*4*]. Large-scale testing, for example, 3.048-m (10-ft) columns, can be conducted at a laboratory in England. No correlation data are available for these two independent laboratories.

Conclusions

A series of carefully designed and controlled fire tests were conducted to determine the feasibility of using small-scale (that is, 0.92-m [3-ft] columns) ASTM E 119-81 tests instead of full-scale tests. The test results confirmed the viability of these small-scale tests for specific applications. The tests are reproducible and they correlate well with the full-scale test as evidenced in Table 3.

At the present time, the major use for small-scale tests is during the development of new fire resistant coatings. The tests provide a reliable guide to the performance of a new coating and at a significantly lower cost than full-scale tests.

Small-scale tests are also gaining wider acceptance by various codes or other regulating agencies. These cases are usually for highly specific uses.

However, we feel that the real opportunity for widespread use of small-scale ASTM E 119-81 tests will be in uses similar to the original AISI test program [*5*]. New fire resistant coating systems can be thoroughly evaluated across a wide range of steel cross sections and coating thicknesses by means of a relatively few full-scale tests at key points, with the remaining rating points filled in by a combination of small-scale tests and theoretical calculations.

VTEC is testing fire resistant coatings for use by the petrochemical and oil industries, following the procedure established in 1975, and will continue to do so until a uniform standard is adapted.

However, it does seem that with every year of study, the proposed ASTM methods get increasingly complex and will therefore become a very expensive test. Such a test will prevent many new products from ever being tested, let alone reach the market. This is a situation that now exists. A complete series of full-scale ASTM E 119-81 tests is required before a new product can enter the commercial and industrial fire resistive market.

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DISCUSSION

Recorded Discussion

R. Berhinig[1]—Neil, one of the items that you mentioned was some full-scale results, 163 min for time of end point. You said, that UL wrote that it may be an error. Just for the record, I think I wrote the letter, and the reason that we wrote the letter was that at the time we were doing some preparative work trying to develop a theoretical program of inflation, and we had the error, it looked like an error, the difference between the test result and the empirical numbers. We asked that maybe this test should be rerun to verify the test data for the empirical analysis. As it turned out, the error was more in the empirical analysis than in the test data. I just wanted to make that point clear in terms of the comparison with certain numbers is developed with the equipment. The letter, which I believe is in the report, is a little bit misleading in terms of why it was written and what its been used for. Again, it was a comparative study and an empirical analysis that we were trying to establish a correlation between.

Dave Moore[2]—I guess you say small scale, nothing has been reduced or scaled down other than length of the specimen.

Neil Schultz—That's correct.

Dave Moore—Secondly, do you have a number that would give us an indication of just how much savings there is in this rather than in full-scale tests.

Neil Schultz—Well that depends upon how many columns are being tested and the program itself, but there is a marked saving involved.

David Moore—Have you cut the price in half, regardless of the details of the test?

Neil Schultz—I'd say that's a good place to start.

M. E. Herrera[3]—Can you tell me what the retained moisture at constant weight of the oxychlorides was when you tested?

[1] Underwriters Laboratories, Inc., 333 Pfingsten Rd., Northbrook, Ill. 60062.
[2] Mobil Research and Development Corp., P. O. Box 1026, Princeton, N. J. 08540.
[3] American Energy Products Corporation, 8210 Industry Ave., Pico Rivera, Calif.

Neil Schultz—I wasn't involved in that program with AISI. I'm just taking data from the report.

Chris Magdalin[4]—I noticed that the furnace control thermocouples consisted of one layer symmetrically placed around the column. Is this correct, or did you span the length of the column?

Neil Schultz—That's correct. However, an extensive amount of probing of the thermal profile of the furnace was done to establish that it is uniform throughout, and at that point we only established four thermocouples were needed. We do have the capacity to put more in if so desired.

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[4] Carboline Company, 350 Hanley Industrial Court, St. Louis, Mo. 63144.

Otto K. Gratzol[1] *and Mike C. Diliberto*[2]

A Comparison of Fire Resistive Coatings in ASTM E 119 and Proposed ASTM E 5 Hydrocarbon Pool-Fire Test Environments

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REFERENCE: Gratzol, O. K. and Diliberto, M. C., "**A Comparison of Fire Resistive Coatings in ASTM E 119 and Proposed ASTM E 5 Hydrocarbon Pool-Fire Test Environments,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 68–93.

ABSTRACT: The exposure of proprietary fireproofing materials and concrete to the proposed ASTM Standard Hydrocarbon Pool-Fire Test Environments (E 5) does not exhibit any significant difference for thermal shock from ASTM Fire Tests of Building Construction and Materials (E 119-76).

The duration of protection is reduced in the hydrocarbon pool-fire environment, but the areas under the furnace time/temperature curves are essentially unchanged. The shorter duration is offset by the area under the curve attributed to the more rapid heat rise for specimens compared with those tested using ASTM E 119. There appears to be a measurable relationship between the proposed ASTM E 5 hydrocarbon pool-fire and ASTM E 119 tests, which provides data to forecast the result of one to the other for a given furnace and set of circumstances.

This work was undertaken to compare the effects of the proposed ASTM E 5 simulated hydrocarbon pool-fire on fire resistive coatings and poured-in-place concrete versus the standard ASTM E 119-76 time/temperature criteria. Specimens of similar construction were tested in both environments. A hose stream, similar to that used in petrochemical industry fire-fighting practices, was used on the specimens tested in the hydrocarbon type fire to evaluate the erosive effect and thermal shock characteristics of the generic proprietary products in the marketplace. All specimens showed some erosion.

The test program showed no reason to incur the cost of testing to the proposed ASTM E 5 Hydrocarbon Pool-Fire Test Standard, as 3-h ASTM E 119 rated fireproofing, and 50-mm (2-in.) poured-in-place concrete provided similar correlations between both tests.

KEY WORDS: hydrocarbon pool fire, thermal shock, hose stream, cementitious fireproofing, fire test, fire resistive coatings

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Controversy exists in the Highly Protected Risk (HPR) insurance industry, as well as within the petrochemical industry regarding the effect of a hydrocarbon fire on proprietary industrial fireproofing products now on the market, and on the industry standard, concrete.

The American Petroleum Institute (API) Draft Guideline and Industrial Risk Insurers (IRI) standard for concrete fireproofing is: 50-mm (2 in.), 2.109×10^6 kg/m^2 (3000 lb/in.^{2}) poured-in-place (PIP) concrete meeting ASTM Standard Specification for Concrete Aggregates (C 33-80), ASTM Standard Specification for Ready-Mixed Concrete (C 94-80), and ASTM Standard Specification for Portland Cement (C 150-80). Different fire endurances have been indicated based on the sponsoring agency's furnace, amount of retained water, and type of aggregate used, when tested in accordance with the time/temperature curve in ASTM Standard Methods of Fire Tests of Building Construction and Materials (E 119-76) [*1,2*].

Several major oil companies and industrial insurers consider 50-mm (2-in.) PIP to be the standard for fire protection in areas susceptible to hydrocarbon spill fires. A variance is routinely obtained from the authority having jurisdiction or the project's insurance company to permit use of proprietary products listed by Underwriters Laboratories (UL) for 3 h when tested in accordance with the column criteria in ASTM E 119.

Concern on the part of the petrochemical and insurance industries about the thermal shock caused by the initial heat rise found in a spill fire (ambient to 1093°C [2000°F] in less than (1 min) and the erosion and thermal shock of hose-stream impact used in fighting this type of fire prompted this research.

This paper compares the fire endurance of several generic proprietary products with concrete in the ASTM E 119 environment and in a fire environment similar to that proposed by the ASTM Committee E05 on Fire Standards concerned with designing an ASTM Standard for Hydrocarbon Pool-Fire Test of Fireproofing Materials.

The generic fireproofing materials are:

Specimen 1—portland cement with exfoliated vermiculite without fiberglass reinforcing.

Specimen 2—portland cement with proprietary fillers including fiberglass reinforcement.

Specimen 3—magnesium oxychloride based proprietary cement.

Specimen 4—intumescent epoxy.

Specimen 5—dense concrete.

Equipment

The furnace used in these tests has a 1.2- by 1.2- by 1.8-m (4- by 4- by 6-ft) fire area and is powered by twelve natural gas burners, each having a capacity of 90.72×10^6 cal/h (360000 Btu/h). Primary combustion air is induced by an Eclipse® turboblower. The furnace is automatically ignited.

The furnace is lined with a soft refractory that allows for thermal shock testing of the fire resistive coatings. When conducting thermal shock tests, the furnace is turned off at a predetermined time. After a 4¾-min safety purge, the furnace can be automatically reignited and fire testing resumed without damaging the furnace refractory. The furnace is designed to duplicate the ASTM E 119 fire environment as well as the proposed ASTM E 5 environment.

A Doric® Degitrend 235 data logger and two Leeds and Northrup Speedomox Strip Chart recorders provided records of the tests.

Eight 14-gage Type K thermocouples in Inconel® tubes placed 305 mm (12 in.) from the specimen were used to control the furnace temperature in accordance with the ASTM E 119 time/temperature curve shown in Fig. 1. These thermocouples were also used to limit the furnace temperature to 1093°C (2000°F) in the hydrocarbon fire environment. The temperature rise to the 1093°C (2000°F) level depends on the rate of heat absorption of the specimen. Heat input was 108.3×10^9 cal/h (4.3×10^9 Btu/h) during the "high rise" phase of the test. The furnace temperature reaches 1093°C (2000°F) in 2 min with no specimen, 12 min for a bare specimen (unprotected steel absorbs the most heat), and 6 to 7 min for a protected specimen.

Twelve 20-gage Type K thermocouples, peened into the specimen, were

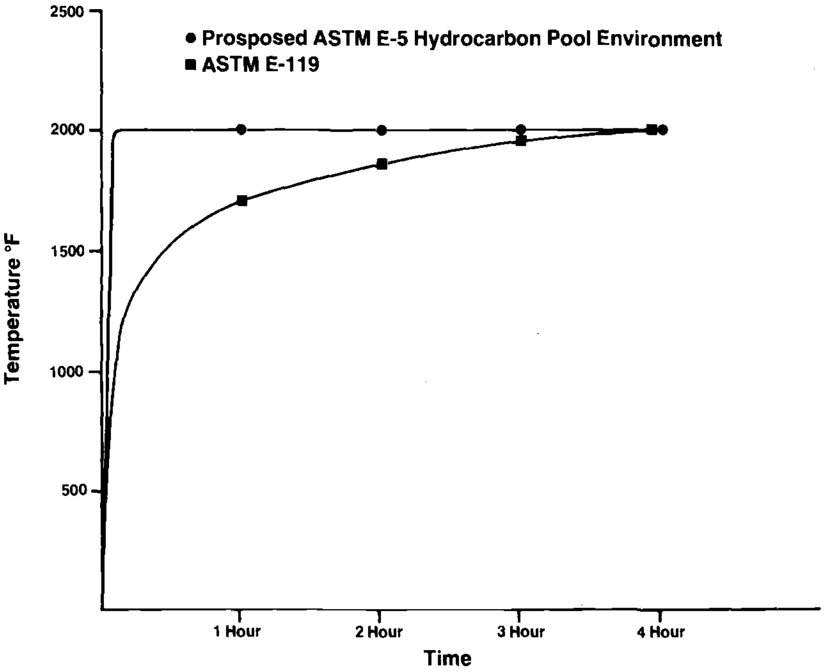

FIG. 1—*Relationship between ASTM E 119 and proposed ASTM E 5 Hydrocarbon Pool Environment.*

used to record the temperature rise of the steel. The flange edge thermocouples were 1.27 cm (½ in.) from the edge. See Fig. 2.

Specimen Preparation

The test columns were 1.52 m (5 ft) tall, W10X49 mild steel with 35.6-cm^2 (14-in.^{2}) steel caps welded to the top and bottom.

Specimen 1

Specimen 1 was portland cement with exfoliated vermiculite without fiberglass reinforcing.

Fireproofing was installed in accordance with the manufacturer's recommended petrochemical specification, which requires installation of 50-mm (2-in.) hexigonal chicken wire applied continuously in a contour fashion with mechanical attachment. The chicken wire was pulled away from the steel 1.27 cm (½ in.). Screeds were then attached to the specimen to ensure a correct thickness of 3.65 cm (1$\frac{7}{16}$ in.), the 3-h UL listed thickness. The product was applied in three coats, all within the manufacturer's published application parameters (Fig. 3*a*).

Specimen 2

Specimen 2 was portland cement with proprietary fillers including fiberglass reinforcement.

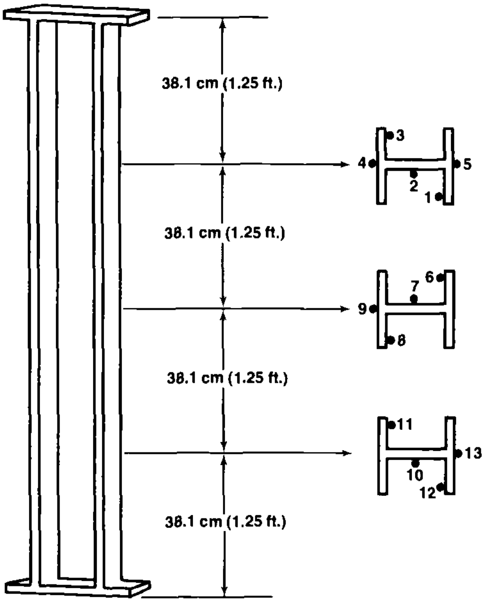

FIG. 2—*Specimen thermocouple placement.*

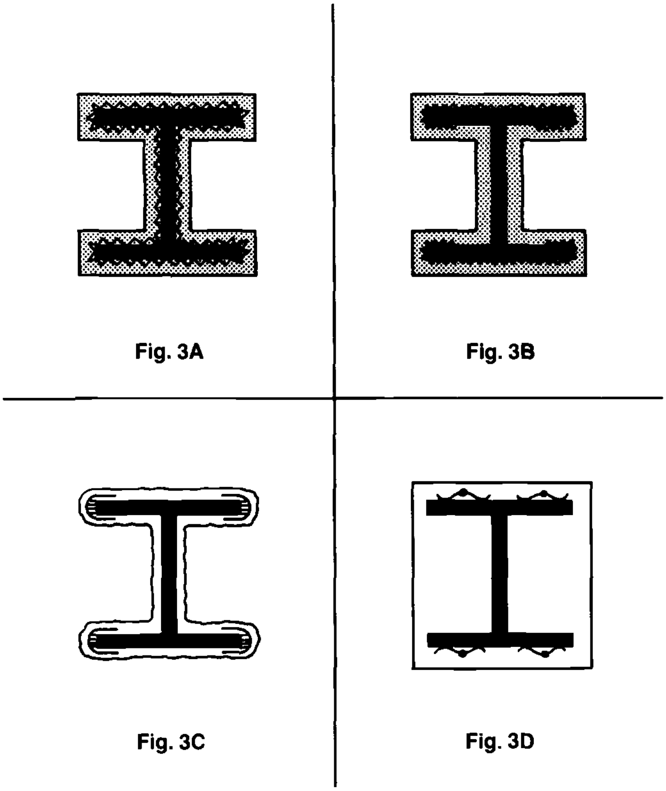

Fig. 3A

Fig. 3B

Fig. 3C

Fig. 3D

FIG. 3—*Specimen cross sections.*

Fireproofing was installed over 1.8 kg/m^2 (3.4-lb/yd^2) diamond metal lath. The lath was attached to the outside flanges and extended 3.8 cm (1½ in.) onto the inside flange edge. Attachment was by means of beam furring clips. Screeds were used to obtain a thickness of 3.17 cm (1¼ in.) in accordance with the manufacturer's 3-h UL listing. The product was applied in two coats (Fig. 3*b*).

Specimen 3

Specimen 3 was a magnesium oxychloride based proprietary cement.

Fireproofing was installed similarily to Specimen 2 at a thickness of 2.2 cm (⅞ in.) in accordance with the 3-h UL listing for this product.

Specimen 4

Specimen 4 was an intumescent epoxy.

Fireproofing was applied over an epoxy polyamide primer. Proprietary corner bead, with 2.5- by 1.27-cm (1- by ½-in.) 3.6-kg (8-lb) density mineral fiber batts to protect flange edges were installed. A minimum of 0.48-cm

(3⁄16-in.) intumescent epoxy was spray applied in one coat, similar to the manufacturer's 1-h UL listing. See Fig. *3c*. No 3-h UL listing is available for the specimen tested in the ASTM E 119 environment. The specimen tested in the high rise environment had a total thickness of 1.27 cm (½ in.) minimum, applied in two coats, similar to the manufacturer's 1-h "pit fire" design.

Specimen 5

Specimen 5 was a dense concrete.

Concrete fireproofing was applied. Two 0.635-cm (¼-in.) diameter slab bolsters were welded onto each outside flange. The specimen was put into a form and dense concrete, meeting the API and IRI specifications mentioned in the introduction, with 0.95-cm (⅜ in.) torpedo gravel, aggregate was poured and vibrated into place. See Fig. *3d*.

Procedure

Fire Tests

One set of specimens was tested in strict accordance with the ASTM E 119 column test with the exception of specimen length. The standard uses a 2.44-m (8-ft) column, however, for this test a 1.52-m (5-ft) column was used because of furnace height limitations. However, previous testing between testing laboratories has indicated end effects are trivial between the 1.52- and 2.44-m (5- and 8-ft) test columns.

The second set of specimens was tested using the hydrocarbon time/temperature curve described in Fig. 1. Once the steel reached 661°C (1200°F) at a single thermocouple, or 538°C (1000°F) average of a group of thermocouples, the furnace was turned off and purged. When the furnace temperature was reduced to 538°C (1000°F), the furnace was opened, and the specimen was moved to the hose-stream impact area. The total time from furnace shutdown to hose stream on all specimens did not exceed 15 min.

Hose-Stream Test

The specimen was positioned with a flange face presented at a 45° angle to the hose stream. A 2.86-cm (1⅛ in.) diameter Akron combination nozzle positioned 6.1 m (20 ft) from the specimen, with straight stream nozzle pressure of 52.7×10^3 kg/m^2 (75 lb/in.^{2}) flowing 227 L/min (60 gal/min) was used for these tests. Water in a solid stream was played evenly over the surface of the specimen for 20 s, the equivalent of 5 min/9.3 m^2 (5 min/100 ft^2) of target (Table 1).

Results

All products tested gave reduced levels of fire endurance compared to the listing generated at UL using the ASTM E 119 time/temperature criteria (Table 2).

TABLE 1—*Industry hose-stream tests.*

Parameters	API	Test Used	ASTM E 119
Water pressure, kg/m^2 (lb/in.^{2})	35.1 K (50)	52.7 K (75)	21.1 K (30)
Duration minutes/9.3 m^2 (100 ft^2) of specimen, m (ft)	5	5	2.5
Distance to specimen, m (ft)	6.25 (20)	6.25 (20)	6.25 (20)
Nozzle diameter, cm	2.85	2.85	2.85
Nozzle type	smooth bore	Akron	standard playpipe
Flow rate, L/min	...	220	...

All products had reduced fire endurance compared to the ASTM E 119 environment in the hydrocarbon fire except concrete. The large crack in the concrete column in the ASTM E 119 series caused it to fail prematurely (Table 3).

All specimens demonstrated erosion from the hose-stream test (Fig. 4).

Discussion of Results

The reduced fire endurance of the specimens obtained in the test furnace compared to UL listings using the ASTM E 119 test criteria is a function of the type of burner system used in the furnace and the type of refractory used. The UL furnace produces a "rolling or licking flame" while this test furnace has a more intense flame pattern that impinges directly on the specimen. Also, calorimeter readings in this furnace during ASTM E 119 tests at 30 and 60 min are 111 and 120 kW/m^2 (587 and 636 Btu/ft^2/min). The total average heat flux was 93 kW/m^2 (543 Btu/ft^2/min). The UL furnace produces 87 and 115 kW/m^2 (459 and 607 Btu/ft^2/min) at the same time intervals [*3*]. This is a function of the heat absorption of UL fire brick versus this furnace's reflective refractory blankets. Since the major source of thermal (radiant) heat flux comes from the furnace walls, the difference in heat flux between different types of furnaces will decrease as time after test initiation increases.

As expected, the hydrocarbon series produced shorter periods of fire endurance. The unexpected result is the percent reduction in fire endurance ranging from 6 to 20% when compared to the percentage increase of 48% in heat flux. We recorded an average total heat flux of 195 kW/m^2 (1033 Btu/ft^2/min) in the hydrocarbon test, with a reading of 210 kW/m^2 (1066 Btu/ft^2/min) at 17 min into the test. The average radiant flux was 183 kW/m^2 (967 Btu/ft^2/min). These heat fluxes are at the high end of those measured in various actual and simulated pool fires and exceed the proposed hydrocarbon standard by 12% [*3*].

Examination of the area under the furnace temperature curve for each fireproofing type shows a closer correlation than that produced by heat flux. Using the data obtained by counting squares under the curve from the specimen failing by section average (point failure data were not used) in a linear

TABLE 2—*ASTM E 119 test series summary.*

Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
		TIME TO FAILURE, MIN		
160	155[a]	133[a]	25[b]	133
		MODE OF FAILURE		
Midsection average	top section average	top section average	single point top section	single point failure
		COMMENTS		
Before burn many fine shrink cracks were visible.	No shrink cracks were visible before burn.	Before burn no shrink cracks visible.	Before burn smooth continuous surface. No cracks.	Surface was hard and smooth. No shrink cracks visible.
At 20 min into test numerous hairline cracks expanded and more became visible. At 80 min entire specimen covered with cracks.	At 105 min a 45.7-cm (18-in.) crack formed on flange edge. At 120 min a 20.3-cm crack formed near the top thermocouple on flange.	At 120 min cracks formed near flange edge, 0.64 (¼ in.) wide penetrating to lath.	Intense smoke generated. Cracks appearing around top section. Flaking and delamination in middle of web. Top section average failure at 33 min.	At 5 min surface spalling began. At 140 min a large crack approximately 1.27 cm (½ in.) wide had opened near flange edge. In addition, many small cracks opened up.

[a] Data obtained from previous correlation studies.

[b] The thickness is for a UL listing of 1 h. The other specimens have a nominal 3-h UL listing.

TABLE 3—*Hydrocarbon test series summary.*

Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
		TIME TO FAILURE, MIN		
141	129	125	11[a]	138
		MODE OF FAILURE		
Midsection average	midsection average	midsection average	single point top section	midsection, average
		COMMENTS		
At 30 min many hairline cracks not previously visible had formed. Cracks continued to widen at 90 min. Entire surface was covered with network of cracks.	At 60 min no cracking visible, surface was flaking. At 120 min surface flakes larger and more pronounced. No cracks to substrate.	At 45 min cracks developed on two flange edges. Small cracks were visible.	Intense smoke made observation impossible for 5 min. Large crack visible on flange at 5 min. Top section average failure at 46 min. Product continued flaming after furnace shut off.	At 5 min a square foot section spalled off flange face. Small areas of spalling evident over entire surface. At 15 min a long vertical crack occurred. At 60 min many small surface cracks visible.
		HOSE STREAM		
No steel visible, erosion over most of surface 0.63 cm (¼ in.) deep.	Lath exposed on 45% of flange edge. Erosion over most of surface.	Extensive erosion, most of surface is visible.	Char remained intact except for area around major crack.	Extensive spalling exposing both flanges. No explosive spalling.

[a] Thickness of product is in accordance with a 1½-h UL listing. The other specimens use a 3-h UL listed thickness.

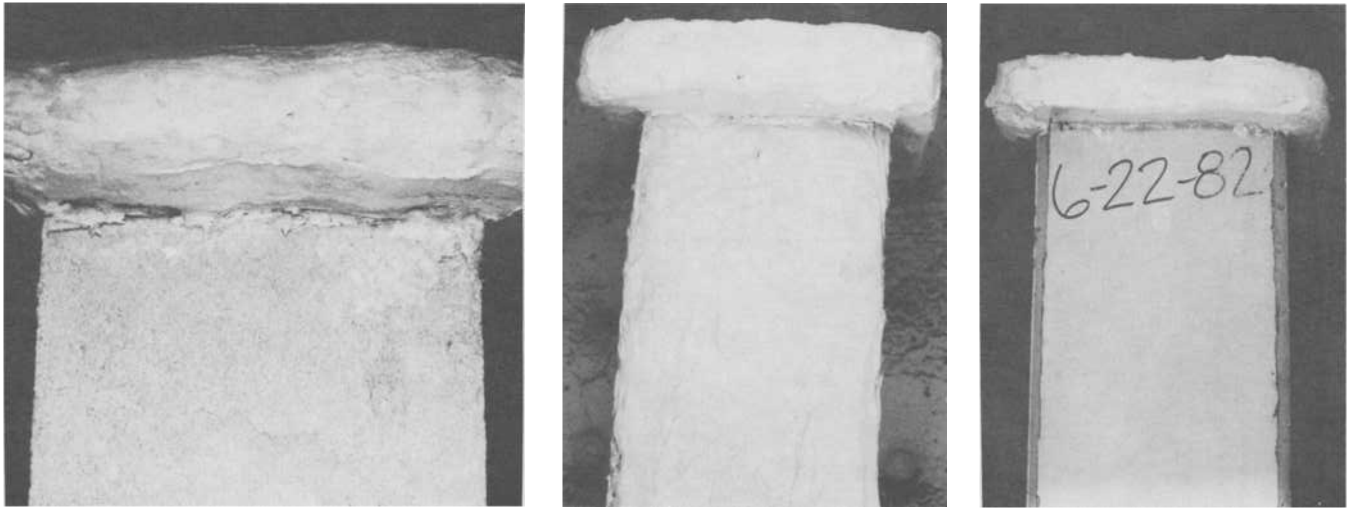

FIG. 4a—*Typical results proposed by ASTM E 5 criteria. Specimens before fire test:* (Left) *proprietary cementitious, Specimen 1;* (Center) *intumescent epoxy, Specimen 4; and* (Right) *dense concrete, Specimen 5.*

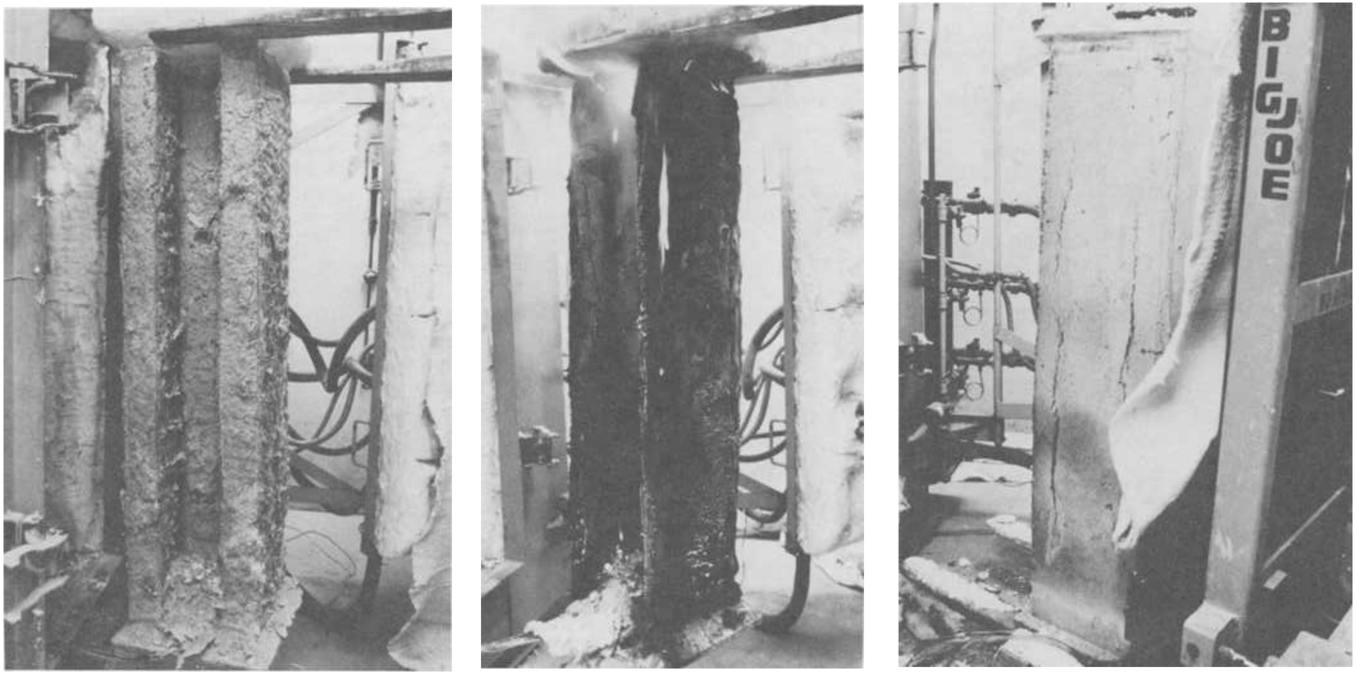

FIG. 4b—*Typical results proposed by ASTM E 5 criteria. Post burn specimens:* (Left) *proprietary cementitious, Specimen 1;* (Center) *intumescent epoxy, Specimen 4; and* (Right) *dense concrete, Specimen 5.*

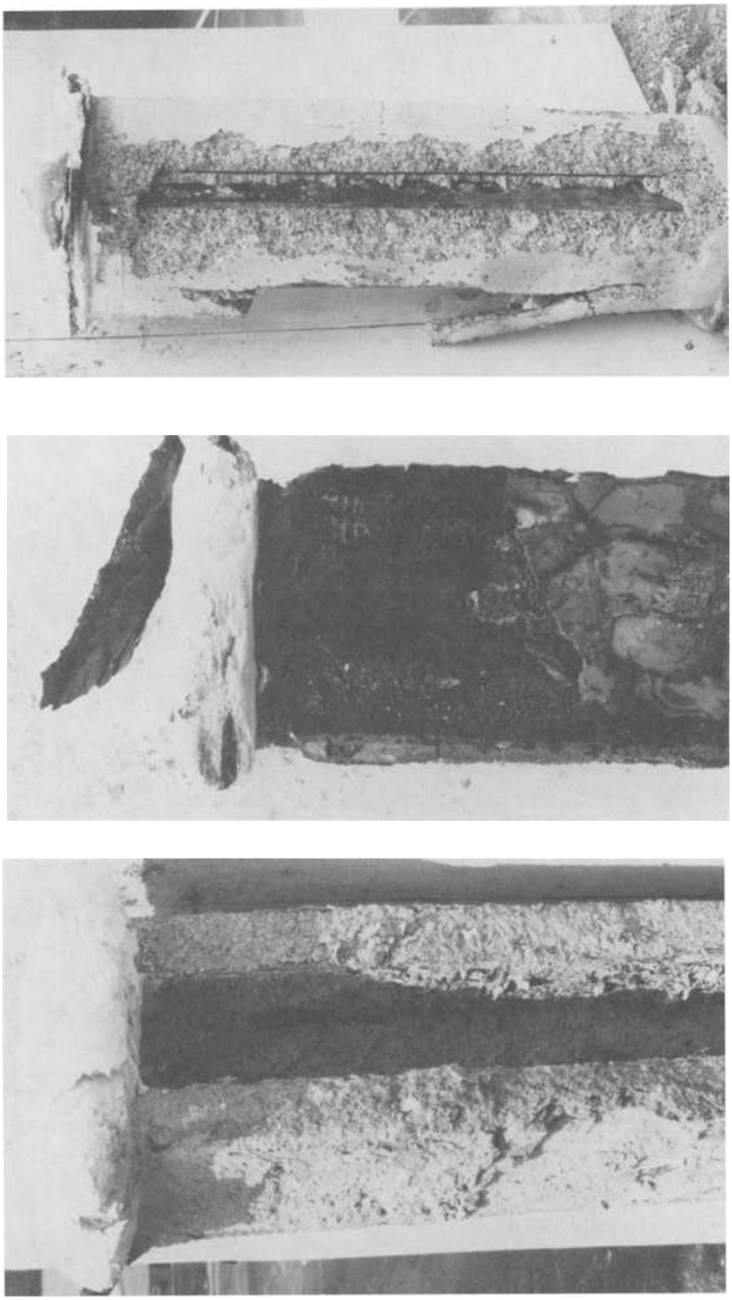

FIG. 4c—*Typical results proposed by ASTM E 5 criteria. Post hose stream specimens:* (Left) *proprietary cementitious, Specimen 1;* (Center) *intumescent epoxy, Specimen 4; and* (Right) *dense concrete, Specimen 5.*

regression model provides a mean of 1148, a standard deviation of 15, and a coefficient of determination R^2 of 0.98. Caution is advised since the specimen size is three, but previous work using other products gives a mean of 841, a standard deviation of 54 with an R^2 of 0.99. The previous correlation work was for a lower level of fire endurance than that investigated in this research. These data imply a closer correlation between the current standard and the proposed standard, particularly in light of the minimal effect of thermal shock observed on the two sets of specimens.

All products tend to erode under hose-stream impact. The erosion is particularly prevalent where the fireproofing material is evenly reacted throughout its entire thickness. The specimens that had severe cracking failed by thermal shorts, leaving uncalcined material to absorb the impact of the hose stream.

The hose-stream test used is a compromise between the suggested method in the API Draft Guideline on Fireproofing Practices in Petroleum and Petrochemical Processing Plants and the ASTM E 119 hose-stream test (Table 1).

The compromise was caused by the availability of equipment from the local fire department. Extrapolations from insurance industry spacing requirements, water monitor locations, and effective reach of nozzle types indicate the tests used give similar results to the type of erosion expected in typical plant fire-fighting practice. Thermal shock effects would be more pronounced because of higher flow rates available in plant water systems [*4–6*].

It was decided to perform the hose-stream test after the completed fire test rather than half way through the test as is done using a second specimen in ASTM E 119. The post burn hose stream is the cause of high erosion rates, relative to results that would be expected using ASTM E 119.

The results of the intumescent epoxy system are included for comparison purposes only. The two specimens have different thicknesses of material caused by a pot life problem.

Conclusions

The area under the furnace temperature curve measured to the sample failure point is essentially constant between the ASTM E 119 and the proposed ASTM E 5 hydrocarbon standard at the 3-h ASTM E 119 level of endurance. The faster temperature rise of the hydrocarbon fire is offset by the shorter duration to endpoint.

There is no difference in product response to the rapid heat rise of the hydrocarbon fire compared to that of ASTM E 119.

Three-hour ratings generated using ASTM E 119 give equivalent fire protection when compared to 50-cm (2-in.) massive PIP concrete in hydrocarbon fires.

The equivalence of endurance and the lack of measurable effect of the rapid temperature rise on the specimens indicate no reason to continue the work on the hydrocarbon fire test, except with regard to hose-stream testing. The current ASTM E 119 time/temperature criteria provides an adequate test structure at the 3-h fire endurance level.

Limitations of Research

1. All specimens received an average one-month cure cycle. The retained moisture in the concrete specimen probably provided better endurance than normally expected, however, only minor spalling was encountered. The specimens were not tested for weather resistance.
2. All systems were installed in accordance with manufacturer's instructions but were not installed by the individual manufacturers. Ease of installation varied with cementitious systems being easiest to apply.

Acknowledgments

The authors thank the Brentwood Fire Department, Brentwood, Mo., for their cooperation in this study.

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[*5*] Oil Insurance Association, General Recommendation for Spacing in Refineries, Petrochemical and Gasoline Plants, Hartford, Ct., Aug. 1972.
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DISCUSSION

E. Bruce Belason[1] (*written discussion*)—I agree that the need for new tests must be carefully examined. However the data presented in this report fails to substantiate the conclusion that the ASTM E 5 pool-fire test is unnecessary.

Concerning hose-stream tests, the data and logic presented have left major questions unanswered.

Finally, fabricating and testing competitors' materials carry with them the risks of technical errors caused by unfamiliarity and bias caused by commercial interests, and this report succumbs to both.

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[1] Director, Fire Products, AVCO Specialty Materials Division, Lowell, Mass. 01851.

Fire Tests

Test Population

The test population is too small (three materials and 1 test per environment each). Even the authors recognize the limitations. Specific comments on limitations such as:

1. One test per environment per material is simply not enough.
2. Of the three materials considered in the final population, one was a competitor's. This introduces the variable of whether or not the authors had the expertise to properly fabricate the material (note that this was exactly the reason for deletion of Specimen 4 from the population).
3. The remaining two materials were manufactured by one author's company. But, the reported ASTM E 119 test results for these two materials were obtained from specimens fabricated and tested at a time other than this test program. Thus the variables of other fabrication and test techniques, and personnel are introduced.
4. The population consists of only freshly fabricated nonweathered specimens. Reference *1* indicates this factor should be considered. Reference *2* clearly states that the physical integrity of certain types of concrete can be seriously impaired in certain types of environments.

Pool-Fire Test as Conducted by the Authors

Key differences versus the proposed ASTM E 5 conditions are:

1. The authors used only gas temperature to define and control the fire environment. This is inadequate. An essential part of the ASTM E 5 pool-fire method is that it specifies heat flux shall be measured at eight points every 5 min and shall be used as the primary method of control of the fire environment along with gas temperature.[2] The authors do report some heat flux values. However a critical failing is that they do not specify how the heat flux is measured.[3]

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[2] Note that this agrees with the major conclusion expressed in the National Bureau of Standards Report NBS-GCR-76-50 entitled, "A Theoretical Analysis of the ASTM E 119 Standard Fire Test of Building Construction and Materials," prepared by the Stanford Research Institute: "Exposure severity is given indirectly and incompletely by specification of the furnace temperature. The true measure of severity is given by the heat flux, which is a function of the furnace temperature and emissivity . . . Our overriding conclusion is to recommend that future improvements of the ASTM E 119 test focus more on the control, measurement, and specification of the heat flux condition rather than the ambient gas temperature history." There is increasing agreement within ASTM Committee E05 that the E 119 test environment does need tighter controls. They seem to be taking an alternate approach of more tightly defining the furnace and fuel parameters.

[3] The ability to accurately and reliably measure heat flux is regarded by many on the ASTM E-5 Pool Fire Task Group as the key technical point that must be solved in order to develop a standardized test method. A 2-day workshop was conducted on this subject by the ASTM E-5 Pool Fire Task Group in 1982.

2. The ASTM E 5 pool-fire method specifies achievement of an average heat flux of 173 kW/m^2 (15.3 Btu/ft^2 s) within 5 min. The authors achieved 201 kW/m^2, 17 min into the test, thus less than ⅓ the thermal shock, and thermal shock is probably the key effect on fireproofing performance in ASTM proposed E 5 pool fire versus ASTM fires. Further, if no specimen was present when this 201-kW/m^2 measurement at 17 min was made, the thermal shock could have been even less, since, as the authors report, it takes the furnace longer to heat up with a specimen present.

ASTM E 119 Test as Conducted by Authors

Presented in Table 1 are the paper's data for the three materials remaining in the test population with some observations.

Thus the average difference in ASTM E 119 times between the furnaces of UL and the author is almost twice as large as the difference in ASTM E 119 versus ASTM E 5 pool-fire times in the authors' furnace (31 versus 18 min). It would appear hasty to conclude from this that an ASTM E 5 pool-fire test method is not needed.

This type of difference in ASTM E 119 times for different furnaces is eloquent testimony, per the preceding discussion, that (gas) temperature alone does not adequately define the fire environment. Rather, heat flux must be measured and controlled, and, in fact, the limited heat flux measurements made by the authors imply that its furnace produces a more severe ASTM E 119 environment versus that of ULs, thus probably explaining the difference in the test results versus those of ULs.

A final technical point: referring to the last two sentences of Paragraph 1 of the "Discussion of Results" section, I disagree with the explanation that the difference in optical reflectivity of the walls of the UL versus the authors' furnaces is the cause for the heat flux differential. If a furnace is fully enclosed (most furnaces are; small viewing points can be neglected), then the thermal radiation from the walls will be black body radiation at the surface temperature of the walls, regardless of the reflectivity of the surface of the wall (assuming the wall has zero transparency), as explained in Ref *3*. Thus

TABLE 1—*Data for the three materials remaining in the test population with some observations.*

Specimen	UL E 119 Test Time, min	Carboline E 119 Test Time, min	Observation: Difference, UL Versus Carboline E 119, min	Carboline E 5 Pool-Fire Test Time, min	Observation: Difference, Carboline E 119 Versus Carboline Pool Fire, min
1	180	160	20	141	19
2	180	155	25	129	26
3	180	133	47	125	8
Avg	180	149	31	132	18

"color" of the furnace walls is unimportant, and the last sentence of Paragraph 1 of the "Discussion of Results" section could be more correctly rephrased, "Since the major source of thermal (radiant) heat flux to the specimen comes from the furnace walls, the difference in heat flux between different types of furnaces will decrease as time after test initiation increases since the thermal inertia of the walls will be increasingly overcome." Note that this is exactly what the heat flux data show for the furnaces of UL versus the authors'.

Data Analysis and Conclusions

1. Concrete (Specimen 5 of the program) actually performed longer in the ASTM E 5 pool-fire than the ASTM E 119 fire. However, the authors discard the data for this material because "the large crack in the concrete column in the ASTM E 119 series caused it to fail prematurely." Unless the concrete was improperly fabricated, cracking is a legitimate failure mode. Thus why discard the data point? If one chooses to conduct a single specimen test program, then one must be prepared to use all legitimate data so obtained.

2. The conclusion that thermal shock has no significant effect on test results cannot be made since, as previously discussed, the thermal shock proposed in the ASTM E 5 pool-fire method (173 kW/m^2 in 5 min) was apparently not obtained in the authors' tests.

3. The paper concludes that fireproofing time can be correlated with area under the time-temperature curve. The rationale for this is given in Paragraph 3 of the "Discussion of Results" section, "Using the data obtained by counting squares under the curve for the specimen failing by section average (point failure data were not used), "Why not?" in a linear regression model provides a mean of 1148, a standard deviation of 15, and an R^2 of 0.98." I pose the question, 1148 of what? What are the units of 1148? Is 1148 for all six tests or for the pool-fire and ASTM E 119 test for a given material?

The next sentence states: ". . . previous work using other products gives a mean of 841. . ." Since 841 is 37% different than 1148, how does the 841 support the 1148? Note here again is a reference to key data not reported or identified in the paper.

4. From a heat transfer viewpoint, it would be more logical to see if there is a correlation between performance time versus total heat exposure of the material, that is, integrated area under the heat flux rate versus time curve (Btu/ft^2 × h = Btu/ft^2). This would correlate incident kW/m^2 (Btu/ft^2) versus performance time (assuming thermal shock effects do not enter, which is probably invalid for some materials, such as cracked, unreinforced, and water-soaked concrete), instead of the °C/h (°F/h) exposure versus performance time, which the authors tried.

5. Finally the authors neglect to offer any rebuttal to the well publicized work of Corona and Warren [*4*], where 50 mm (2 in.) of concrete on a steel

substrate of equivalent heat sink capacity as a 10WF49, gave only 1-h protection in a hydrocarbon fire, versus a nominal 3-h in the ASTM E 119 fire. Reference *1* also cites differential performance for concrete in ASTM E 119 versus pool fires.

Hose-Stream Tests, Results and Conclusions

The paper describes a considerable effort devoted to hose-stream testing of the column stubs after hydrocarbon fire exposure. However, several factors are lacking.

Lack of ASTM E 119 Historical Basis

There is not now, nor has there ever been, a requirement in ASTM E 119 for hose-stream testing on individual structural members. In fact, there is a current trend towards reducing or eliminating the hose-stream test from ASTM E 119—about five years ago the requirement for hose-stream tests on floor/ceiling assemblies was deleted. The only constructions that currently require hose-stream tests are walls and fire doors. It is also worthy to note that the ASTM E 119 historical origin and use of hose stream provide a uniform mechanical load on a surface to test its strength against puncture (and thus spreading of the fire), not to evaluate strength of fire-exposed fireproofing.

Lack of Current Consensus for Hose-Stream Test

The proposed ASTM E 5 pool-fire test once contained a hose-stream test as an optimal requirement. However, at the Dec. 1981 Task Group meeting it was voted, with only one negative vote, to delete it since it was not a mandatory requirement, and there was too much controversy over the test conditions, acceptance criteria (see 3 the following), and so forth. Voting with the majority were a building code official, an insurance industry official, and a member of a major oil company.

Test Conditions and Performance Criteria

To illustrate the controversy over test conditions and acceptance criteria, the following comments are offered with reference to the authors' paper:

1. Why apply the hose stream after the fireproofing material has done its job and protected the steel to its limit temperature of 538°C (1000°F). If there is concern that an attempt to extinguish the fire at some time, which is only a fraction of the fireproofing's rating, will knock the fireproofing off (thus reducing total fireproofing capability should the fire resume), then the test method should require hose-stream exposure after some fraction of the fireproofing's rating (for example, half). This is how the ASTM E 119 hose test is conducted on walls and fire doors.

2. The hose-stream condition used consisted of a high-pressure solid stream applied 6 m (20 ft) from the specimen. This is not consistent with the condition used to fight a fire in an Hydrocarbon Processing Industry (HPI) unit. First, the objective is not to "punch a hole" in the fire, but rather to wet as large a surface as possible with a given flow rate of water—this means generating a spray, as with a fog nozzle. Second, a fire in an HPI unit that lasts any appreciable amount of time tends to be large, thus fire fighters are unlikely to be as close as 9 m (20 ft) but rather are much further back and lob in a stream of water that will impact the structure as a spray.

3. The hose-stream test data reported by the authors are subjective; it is not supported by quantitative test data nor does it suggest procedures, data analyses, or criteria to "pass" or "fail" a given fire protective coating.

Performance Comparisons Among Generic Coating Types

The following comments coupled with previously mentioned specimen deficiencies, indicate that the authors would have been well advised to report data on, and draw conclusions from, Specimens 2 and 3 only.

Application Procedure for Intumescent Epoxy Specimen

Table 1 of the paper contains no data for Specimen 4, only the comment, "not tested because of application problems." It could be interpreted that the intumescent epoxy material was difficult to apply, especially when Paragraph 3 of the "Limitations of Research" section states, "Ease of installation varied with cementitious being easiest to apply." How does this comment qualify as being a "limitation of research?" In actual fact, as the author privately verified, the application problem was the result of a major deviation from the manufacturer's proper application procedure for this product. Note that this also contradicts the sentence in Paragraph 3 of "Limitations" that "All systems were installed in accordance with manufacturer's instructions. . ."

Fire Test Data on Intumescent Epoxy Specimen

Table 2 of the paper states that one thermocouple (measuring steel substrate temperature) reached 649°C (1200°F) in 11 min versus the section average of four thermocouples (including the "11-min" thermocouple) to 538°C (1000°F) of 46 min. It would strongly appear that either there were additional specimen fabrication errors, or the improper thermocouple procedure was used or both, since:

1. It is hard to understand, given the high-thermal conductivity of steel, how such a large disparity in times could be sustained for one thermocouple versus the others, all at the same cross section.

2. Intumescent epoxy specimens require more sophisticated instrumentation procedures (versus cementitious and concrete materials), with which the authors may not be familiar, and which, if not followed, can result in erroneous data.

Comment on Aging of Intumescent Epoxy Specimen

Paragraph 2 of the "Limitations of Research" section contains the comment, "Previous research on aging indicates organic intumescent coatings can lose fire endurance by leaching on long-term weathering."

Once again, contrary to standard technical report procedure, an unidentified reference to data not presented in the paper is given. This statement is totally unsupported and clearly is added for reasons other than technical. Just as it is recognized that there are "limitations of research," it must be recognized that there must be limitations on innuendo and clear attempts to mislead the reader. In actuality, the intumescent epoxy cited by the authors was the first coating ever classified by UL for exterior use (and this classification requires no topcoat), whereas Specimen 3, the authors' own magnesium oxychloride product, is not classified by exterior use.

Concern about weatherability is valid but not in the manner presented in the report.

Other Questionable Comments

1. Tables 2 and 3 of the paper contain copius comments that indicate that a competitor's lightweight concrete (Specimen 1) cracks more than Carboline's lightweight concrete (Specimen 2). It is agreed that, in general, cracking is not desirable. Yet Specimen 1 outperformed Specimen 2 in both the ASTM E 119 and hydrocarbon fires. What conclusions are to be drawn concerning the authors' correlation of cracking versus performance time?
2. Paragraph 3 of the "Abstract" states that the lightweight concrete materials were the least affected by post fire test hose-stream erosion. This appears to be inconsistent with the qualitative remarks of Table 3 which for both light concrete materials contains the comment "erosion over most of surface," versus the comment for the intumescent epoxy, "char remained intact except for area around the major crack."

Conclusion

The authors appear to have lost sight that the purpose of the ASTM E 5 Pool-Fire Test Method is: to provide a method for reliably and repeatably evaluating fire protective coating systems by practically simulating the essential aspects of the high rise hydrocarbon fire environment.

The motivating force behind development of this test method, in fact, has been the hydrocarbon processing industry who have long recognized the deficiencies of the ASTM E 119 fire test in evaluating HPI coating systems [*1,4–6*].

Note that the report actually reinforces the need for an improved standardized test method by virtue of the large reported performance differences in the UL E 119 fire test versus the authors' E 119 fire test.

O. K. Gratzol and M. C. Diliberto (*authors' closure*)—The data in the report show there is no demonstratable affect caused by thermal shock between the two tests. One test predicts the results of the other.

The hose-stream criteria is based on the petrochemical plant fire-fighting technique.

Because of the completeness of Mr. Belason's critique our response is on an item by item basis.

Fire Tests

Test Population

1. All products currently listed by UL were tested, one test per environment, per material per hourly rating.
2. The personnel involved in the application of all the specimens are competent to install the generic types involved in the test. Specimen 4 was deleted because we could not obtain replacements for a batch of short pot-life material in time to allow complete cure. Subsequent to final submission of the report, fresh material was obtained and tested, the results of which are given in the revised report.
3. The fabrication and test techniques were the same for all specimens.
4. We agree that weathering of specimens is an important parameter. A client study prepared by the author you cite as Ref *1*, published April 1976, indicates some intumescent products can lose their intumescent properties on aging. Epoxy intumescents were not made available to them at that time.

Pool-Fire Testing

1. Until consensus can be reached on details of methodology of heat flux measurement, gas temperature is the best way to control the fire environment. At the two-day workshop mentioned in Footnote 3 an agreement was not reached.
2. Our furnace, when run in the "Hi Rise" mode produces a heat flux of 178.8 kW/m^2 (948 Btu/ft^2/min) at 4 min and 203.8 kW/m^2 (1080 Btu/ft^2/min) at 6 min, slightly higher than the proposed standard. These readings are with a 1.6 m (64 in.) tall, 10.2 m (4 in.) diameter pipe coated with a cementitious fireproofing material used as a specimen.

ASTM E 119 Test

The inferences in this section of comments are based on the assumption that UL listed product thickness lasted exactly 180 min in the ASTM E 119 test. This is an inaccurate assumption. In actual practice various thicknesses of fire resistive coatings are tested, a curve drawn, a safety factor is added, and a rating promulgated. Therefore, it is impossible to respond to this section.

We do agree that the last sentence of Paragraph 1 of the "Discussion of Results" section should read, "Since the major source of thermal (radiant) heat flux to the specimen comes from the furnace walls, the difference in heat flux between different types of furnaces will decrease as time after test initiation increases because the thermal inertia of the walls will be increasingly overcome." The final version of the report has been so changed.

Data Analysis and Conclusions

1. We chose to report single point failures but did not use the data in our statistical analysis since the goal of the project was to compare the endurance of the materials in two different environments; section failure is a better measure for that purpose.
2. The thermal shock proposed in ASTM E 5 is exceeded in our furnace.
3. The squares under the curve have a unit value of 107°C/min (225°F/min), a "plug" value obtained by superimposing the time temperature curves onto 1.8-cm^2 (¼-in.^{2}) graph paper.

The mean value of 1148 is for the three sets of data, comparing ASTM E 5 to E 119. The remainder of the discussion under Part 3 is adequately covered in the text of our report, when read in context, rather than the edited version presented in your discussion.

4. We agree, as long as temperatures are maintained at a high enough level to simulate a real fire environment.
5. We agree that the work of Corona and Warren [*4*] is seminal to the issue of hydrocarbon industry fire testing. Careful reading of their report shows the specimen geometry, and ratio of concrete to steel mass makes comparison unreasonable.

Hose-Stream Tests, Results and Conclusions

The hose-stream test is an attempt to mimic actual plant fire-fighting techniques.

We agree that close-in fire fighting uses a fog type spray, which has little affect on fireproofing materials. Rather we were demonstrating the effect of the automatic water monitors playing over the fire protected structure. This concept is pointed out under hose-stream requirements [*5*].

Since there is no consensus on pass fail criteria, we reported subjective photographs of the results; see Fig. 4 of the report.

Performance Comparisons Among Generic Coating Types

1. Subsequent to submission of the draft paper further material was obtained and reported on.

2. The "11-min" thermocouple had a crack directly over it, causing it to fail so quickly.

3. Your comment on aging of the intumescent epoxy specimen calls out the need for aged specimens, yet here you decry a comment about aged specimens. Your attention is drawn to Smithers Scientific's Client Study regarding fire performance of aged specimens. Also careful reading of ULs exterior use test allows a product to pass at a 25% reduction in fire protection compared to the control specimen.

Other Questionable Comments

1. Our intent was to compare products on a generic basis. If we were engaged in a campaign of innuendoes we would have used product names as you have. This paper presented data from a test series regardless of which product performed best.

2. Examination of the photograph in Figs. 4*a* through *c* indicates the area around the major crack to be large. The portland cement based products had mostly surface erosion.

Conclusion

See abstract of the paper.

P. H. Woods[4] (*written discussion*)—Since the "thermal shock" factor is found to be minimal, is your furnace capable of assessing this effect? A temperature of 1093°C (2000°F) in 6 to 7 min may not thermally shock your specimens. Moisture content should be important in this test.

O. K. Gratzol and M. C. Diliberto (*authors' response*)—We feel our furnace provides a valid thermal shock to the specimen. A total of 108.3×10^9 cal/h (4.32×10^9 Btu/h) is available to heat the specimen. The Inconel tubes (designed to mimic the UL furnace) provide some temperature lag that may explain part of the slow temperature rise. Note the explanation in the "Equipment" section in the report.

Moisture content is important in the massively poured concrete specimens. Less so in the contour applied products, the thickest of which was 3.65 cm (1$\frac{7}{16}$ in.). All specimens were cured for a minimum of 28 days.

Robert Berhinig[5] (*written discussion*)—How can comparative conclusions be reached regarding a material's resistance to (1) thermal shock and (2) temperature rise when the moisture condition of the specimens was far in excess of the requirements of ASTM E 119 and the proposed E 5 standard?

O. K. Gratzol and M. C. Diliberto (*authors' response*)—Data have shown moisture can significantly affect the thermal shock performance and thermal resistance properties of materials when subjected to an ASTM E 119 exposure.

[4] StanChem, Inc., East Berlin, Conn. 06023.

[5] Underwriter's Laboratory.

We agree that moisture content affects thermal shock performance, normally for the worse: more moisture, more spalling.

The product performance can be compared, as the specimen, generic type to generic type, have similar cure times before testing.

For further information see the previous response to the question of P. H. Woods.

References

[*1*] Rains, W. A., "Fire Resistance—How to Test for It," *Chemical Engineering*, Dec. 1977, pp. 97–98, 100.

[*2*] Delahunt, J., "Corrosion Control Under Thermal Insulation and Fire Proofing," *Corrosion Control by Organic Coatings*, National Association of Corrosion Engineers, 1980.

[*3*] Rohsenow, W. and Choi, H., *Heat, Mass and Momentum Transfer*, Prentice Hall, 1961, p. 335.

[*4*] Warren, J. H. and Corona, A. A., "This Method Tests Fire Protective Coatings," *Hydrocarbon Processing*, Jan. 1975.

[*5*] Committee on Safety and Fire Protection, "Guideline on Fireproofing Practices in Petroleum and Petrochemical Processing Plants," draft version, American Petroleum Institute, Washington, D. C., Aug. 1981.

[*6*] Kayser, J. N., "Testing Fireproofing for Structural Steel," *Chemical Engineering Progress*, Vol. 70, No. 4, April 1972.

Recorded Discussion

Neil Schultz[6]—Was there a difference in the length of endurance in the hydrocarbon fire versus that of ASTM E 119.

Otto Gratzol—Yes there is, but there's a strong correlation factor between the length of time, so you could calculate the area under the curve in the ASTM E 119 and take that to the ASTM E 5 curve, average out your squares, and that will give you your endurance, plus or minus 5 or 10%. Any other questions?

Morris Lieff[7]—Have you discussed your last comment with Bruce Belason, who is chairman of the ASTM E-5 task group on high intensity fires?

Otto Gratzol—Not yet, Hi Bruce! (laughter).

Bruce Belason—Did someone mention my name?

Otto Gratzol—We referenced you in the report too.

Bruce Belason—I am chairman of the task group in ASTM E-5 on hydrocarbon fires. What was the aging preconditioning that you used for the lightweight concrete, the concrete, and the other materials, between the time of fabrication and the time of testing?

Otto Gratzol—Good question. We used a month. It was evident that we did not let the concrete cure long enough. It was still a little bit wet when it went into the furnace. The cementitious products were cured out but I'm almost certain that they were not in equilibrium, so there was a little retained free water in all the specimens.

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[6] Neil Schultz, VTEC LABS, 540 Faile St., Bronx, NY 10474.

[7] Morris Lieff, County College of Morris, Route 10 & Center Grove Rd., Randolph, NJ 07869.

Bruce Belason—Was the one month exposure indoors or outdoors?

Otto Gratzol—Indoor curing? Well, we had them outdoors for about three or the four weeks, but then the rainy season started so we brought them indoors.

Bruce Belason—Because I've seen test results where the materials were water-soaked and tested right after a rainstorm. In particular, I've seen results in concrete, where all the concrete spalled off in 5 min in water soaked conditions. What I'm getting at is the thermal shock effect, which I think is the major difference between the two fire environments (engineering versus hydrocarbon pool fire). If there was something that was going to interject a nonlinearity in the performance, it would be mechanical removal of material caused by thermal shock, which can be a result of the entrapment of moisture in the materials.

Otto Gratzol—That's true Bruce, and it's one of the qualifying conditions. I've got copies of our paper—this is the draft we submitted to ASTM, so it might be different by the time it gets through the editors. They're on the table back there. And it is one of the qualifications we used. You're right, the amount of retained water will affect the spalling. Surprisingly enough, we burned the concrete columns last, and we burned the concrete in the ASTM E 5 environment last because we figured we were going to get explosive spalling and possibly damage to our furnace, but there was no explosive spalling with the concrete specimens, both in the high-rise environment and in the ASTM E 119 environment. A few minutes into the test, we were losing surface scale up to about 6.35 mm (¼ in.) thick. The comment that comes to mind is that there was one 5 min into the test, we lost about a foot at about 6.35 mm (¼ in.) deep. But it wasn't the explosives spalling that we had worried about.

M. E. Herrera[8]—I don't know if I missed anything, but would you indicate the percent moisture before the fire test, that is, the retained moisture.

Otto Gratzol—No, that was Bruce's comment. We did not check retained moisture.

M. E. Herrera—Would you have expected more retained moisture in the lightweight material though, in the vermiculite, rather than the dense concrete.

Otto Gratzol—I don't have a feeling for that. The massive pour, you've got that extra depth in the web, and I'm not sure how fast it migrates out. That's beyond my ability.

Questioner—The 6 or 7 min to approximately 2000°C, do you figure that the period space as opposed to shock treatment?

Otto Gratzol—No I don't think so because it goes up awfully fast there.

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[8] M. E. Herrera, V. P., American Energy Products Corp., 8210 Industry Avenue, Pico Rivera, CA 90660.

Bruce Belason—You refer to hose-stream testing in ASTM E 119, to my knowledge in ASTM E 119 the only requirement for hose stream is one for fire walls.

Otto Gratzol—Right. The hose stream criteria in UL is what I was referring to where they go 2 ½ min/100 ft^2, 30 psi water pressure, 2 ½ min/100 ft^2 and 20 ft and the same size nozzle.

Manuel E. Herrera[1]

A Comparison of Critical Properties of Magnesium Oxysulfate and Magnesium Oxychloride Cements as Used in Sprayed Fire Resistive Coatings

REFERENCE: Herrera, M. E., "**A Comparison of Critical Properties of Magnesium Oxysulfate and Magnesium Oxychloride Cements as Used in Sprayed Fire Resistive Coatings,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 94–101.

ABSTRACT: Magnesium oxysulfate cements although not as strong as magnesium oxychloride cements are better suited for fire resistive uses. Magnesium oxysulfate cements start to decompose at temperatures more than two times higher than magnesium oxychloride cements decompose giving longer fire protection. Their products of decomposition at elevated temperatures are less noxious (sulfur dioxide) than those of oxychloride (hydrochloric acid) and less corrosive.

Weather conditions (humidity, temperature, and wind) during application are not as critical with oxysulfates as with oxychloride, which may partially form unstable magnesium hydroxide instead of magnesium oxychloride. Commonly known as "burnout" or "dry set," this unwanted reaction can be the cause of loss of bond, cracking, loss of volumetric stability, poor physical properties, and corrosion. Since fire resistive coatings are generally light in density, they are not expected to be as strong as flooring products where the oxychlorides are normally used and are superior. For the intended use as fire resistive and insulative coatings, when those properties are compared, magnesium oxysulfate cements are preferred.

KEY WORDS: coatings, magnesium oxysulfate, magnesium oxychloride, fire resistive, volumetric stability, corrosion

In comparing the critical properties of magnesium oxychloride and magnesium oxysulfate cement, it is necessary first to define what is critical in their use as sprayed fire resistive coatings.

To a great extent the end use of a product controls its properties, which in turn are very much controlled by its chemical make up and compounded

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[1] Vice-president, Research and Development, American Energy Products Corp., 667 Brea Canyon Rd., Suite 20-B, Walnut, Calif. 91789

formula, for example, penetration seals and fire resistive barriers in nuclear power plants must be almost completely free of chlorides.

The following properties, not necessarily in the order listed, would be required of fire resistive coatings.

1. Ability to withstand fire conditions and protect the substrate for a maximum period of time.
2. Ability to retain its integrity during and after fire exposure.
3. Ability to bond to different substrates used in building construction, and remain passive and not attack the substrate under normal conditions for the life of the building.
4. Ability to be easily applied during various weather conditions without requiring extraordinary or special precautions.
5. Ability to be applied as received from the manufacturer as a single component, or at the very least, requiring only the addition of water.
6. Ability to resist damage by other trades during normal construction practices.
7. Ability to be easily repaired if damaged, have the repair blend in with the original, and be as effective and long lasting a fireproof coating as the original.
8. Ability to set and harden to its chemically cured state under a wide range of temperatures without requiring special or extraordinary precautions.
9. Contain no corrosive or harmful ingredients, and be nontoxic and nonirritating during and after application.

Experience has shown that the best "chemically formulated compound" can sometimes perform poorly in the field simply because too much emphasis was put on achieving the maximum physical properties, strength, hardness, tensile bond, and so forth and not enough on whether the product's rheological properties made pumping difficult so that excess dilution with water became necessary, or whether the product aerated excessively with overmixing or set too rapidly for proper mixing and pumping, and so forth.

It is believed that magnesium oxysulfate cements are better suited for sprayed fire resistive coatings than comparable magnesium oxychloride cements. Comparison of these properties is shown in Tables 1 and 2.

Strength (Compressive and Flexural)

Research by Demediuk and Cole [*1*], Rai and Garg [*2*], and Food Machinery and Chemical Corporation, (FMC) [*3*] has shown that magnesium oxychlorides are stronger than magnesium oxysulfates.

Abrasion Resistance

Rai and Garg [*2*] in their work have shown that magnesium oxysulfate mortars have only 50% the abrasion resistance as corresponding magnesium oxychloride mortars.

TABLE 1—*Thermal decomposition of neet magnesium oxysulfate.*[a]

Temperature of 100-g Specimen, °F	Percent of Weight Loss	Percent of Weight Loss as H_2O	Percent of Weight Loss as SO_2
Room temperature	...	...	...
500 (5 min)	15.2	14.8	0.4
600 (5 min)	15.6	15.2	0.4
700 (5 min)	16.4	16.0	0.4
1000 (5 min)	34.2	34.1	0.1
1380 (5 min)	35.6	35.5	0.1
1650 (5 min)	37.5	36.2	1.3
2000 (5 min)	44.4	35.7	8.7

[a] °C = (°F − 32)/1.8.

These two properties are very important in flooring compositions, but in fire resistive coatings that contain large volume amounts of insulative lightweight aggregates that lower both the strength and surface hardness of the composition, the differences would be negligible.

Bonding

Delyon [*4*] and Sorel [*5*] in separate works have shown that both magnesium oxysulfate and magnesium oxychloride cements have excellent bonding properties. This obviously is an important property for the coating used to bond to the substrate and to fillers, sands, aggregates, and so forth in the composition.

Volumetric Stability (Expansion, Shrinkage)

Hall et al [*6*] in their work showed that with the selection of a magnesite (MgO) of appropriate particle size and degree of calcination, specification of cure, chelation, and temperature control, magnesium oxysulfates can be designed with permanent volumetric dimensional properties. This is also true of oxychlorides.

This property is very important to avoid either shrinkage cracks or expan-

TABLE 2—*Thermal decomposition of neet magnesium oxychloride.*

Specimen Temperature, °F	Percent of Weight Loss	H_2O	HCL
Room temperature	...	...	...
500 (5 min)	20.3	20.0	0.3
600 (5 min)	21.2	20.8	0.4
700 (5 min)	28.2	27.6	0.6
1000 (5 min)	45.9	26.4	9.5

sion loss of bond in the set cement and is a property that magnesia cements in general have.

Setting and Curing

The following describes setting and curing under various weather conditions and extremes of temperature. Obviously, weather conditions are a limiting factor in the application of any product, but ideally it should be possible, by taking certain precautions, to use a material equally as well in Minnesota in the winter as in Arizona in the summer. Unfortunately, the ideal is never achieved, and, therefore, one should consider the possibility of insufficient, incomplete, or extremely slow chemical set at low temperatures or incomplete and unwanted chemical reactions at hot dry temperatures.

Demediuk et al [7] and earlier researchers, such as Levy and de Wolf [8], found that in the system $MgO\text{-}MCl_2\text{-}H_2O$, four distinct magnesium oxychlorides are formed that are phase and temperature sensitive. In other words, the type of oxychlorides formed depends on both the concentration of the magnesium chloride solution and the temperature as shown in Table 3.

Countless visits to many job sites indicate that the magnesium chloride solution is rarely mixed long enough to assure complete solution when the magnesium chloride flakes are dissolved with water at the job site. This certainly would affect the ratio of the four types of magnesium oxychlorides formed to each other and could affect the physical properties of the cement.

An unwanted chemical reaction, possible during very hot weather or under dry windy conditions, is that some of the magnesium chloride does not react with the hydrated magnesium oxide and can sweat out to the surface in its ionized form, which is corrosive.

Redeker[2] conducted research on the causes of modified burnouts of oxychloride cement decking installed during hot dry weather and found the following. Under X-ray diffraction, pieces of cracked decking contained a high

TABLE 3—*The four major magnesium oxysulfate and oxychloride compounds formed from the system $MgO\text{-}MgSO_4\text{-}H_2O$ and $MgO\text{-}MgCl_2\text{-}H_2O$, respectively.*

Magnesium Oxysulfate[a]	Magnesium Oxychloride[b]
$5\,Mg(OH)_2 \cdot MgSO_4 \cdot 3\,H_2O$	$9\,Mg(OH)_2 \cdot MgCl_2 \cdot 5\,H_2O$
$3\,Mg(OH)_2 \cdot MgSO_4 \cdot 8\,H_2O$	$5\,Mg(OH)_2 \cdot MgCl_2 \cdot 8\,H_2O$
$Mg(OH)_2 \cdot 2\,MgSO_4 \cdot 3\,H_2O$	$3\,Mg(OH)_2 \cdot MgCl_2 \cdot 8\,H_2O$
$Mg(OH)_2 \cdot 2\,MgSO_4 \cdot 3\,H_2O$	$2\,Mg(OH)_2 \cdot MgCl_2 \cdot 4\,H_2O$

[a] Magnesium sulfate solution concentration up to saturation, temperatures 30 to 120°C.
[b] Magnesium chloride solution concentration up to 45%, temperatures 0 to 110°C.

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[2] Redeker, C. W., "A Study on the Causes of Modified Burnouts of Magnesium Oxychloride Cement," private correspondence, 1965.

percentage of magnesium hydroxide crystals, and chemical analysis showed significant amounts of free chloride. On the basis of his long experience with this type cement and his knowledge of practices common in the industry, Redeker postulated that during hot dry weather the applicator, attempting to offset the fast evaporation of water, would use an 18 to 20° Baumé magnesium chloride solution instead of the 22° Baumé normally specified. At this lower phase concentration the dominant crystal formation was the magnesium hydroxide crystal, after which, with sufficient evaporation of moisture, the phase balance would then produce magnesium oxychloride crystals. The results were a cement with considerably lower physical properties and excess of free chloride.

The use of a factory mixed magnesium chloride solution would appear to solve part of the problem, but the large number of drums of solution, which would have to be handled on even a small job, makes this impractical.

Adding the magnesium chloride in a dry form to the magnesium oxide and other dry ingredients has been done by several manufacturers, ourselves included, but magnesium is so hygroscopic and deliquescent that even coating or encapsulating the dry magnesium chloride before mixing with the other ingredients will result in a product with a very limited shelf life, especially when exposed to any dampness during storage. Even though a bag of a magnesium oxychloride cement manufactured as a complete package may appear dry and free of lumps, which would indicate dampness is getting to it, it is very difficult to know if the small aggregate visible in the mix is really aggregate or grains of magnesium chloride that are reacting with the powdered ingredients around them because of moisture picked up by the magnesium chloride during manufacture of the cement. Whatever the reason, this would not be a satisfactory mix. Magnesium oxysulfate cements, on the other hand, lend themselves much more readily to single package mixes. Epsom salts ($MgSO_4 \cdot 7H_2O$) is commercially available in much smaller crystal form than the $MgCl_2 \cdot 6H_2O$. Also, it is considerably less hygroscopic and not deliquescent and has a pH closer to neutral than magnesium chloride. The advantages of a single package mix are obvious. The ratio of the mix is factory controlled. There is no danger of being chemically unbalanced for the reasons stated earlier. Also the convenience of using water from a hose rather than a solution from drums is an important factor.

The importance of the proper chemical balance of magnesium salt and magnesium oxide cannot be stressed enough. Please recall that the four magnesium oxychlorides and the four magnesium oxysulfates (Table 3) formed from the systems MgO-$MgCl_2$-H_2O and MgO-$MgSO_4H_2O$, respectively, are phase and temperature sensitive. Demediuk and Cole [*1*] found that at 30 to 80°C the 3 and 5 form of magnesium oxysulfate are the predominant stable phases formed. By having a factory-mixed single-package cement, the phase variable is very much reduced.

If as Demediuk and Cole found [*1*] that the type of oxysulfate that forms is dependent on the concentration of the magnesium sulfate solution and temperature, then within limits and to a certain extent, a factory-mixed single-package magnesium oxysulfate cement applied during normal weather conditions at normal temperatures can be expected to yield more of the type of magnesium oxysulfate at the magnesium sulfate concentration than research has shown to yield, the 3 and 5 form. The ideal type for fire resistive cements would be the one that has the highest percent of molecularly bound water. This would be the 3 form; $3\,Mg(OH)_2 \cdot MgSO_4 \cdot 8H_2O$, which has eight molecules of water in the crystal or approximately 45% by weight of molecularly bound water. During a fire, this molecularly bound water is an excellent heat sink, and it will require many British thermal units (Btu's) to separate it from the crystal as free water. As free water it will continue to cool the fire by absorbing heat when turning to steam.

Redeker[3] in his research work compared the thermal decomposition of magnesium oxychloride cement to magnesium oxysulfate cement. Both the oxysulfate and the oxychloride neet mixes were cured at a controlled 30 to 40°C to approximate field conditions at normal temperatures and to assure formation of the 3 and 5 phase predominant at this temperature range. This comparison of possibly the single most important critical property for fire resistive cements shows the superiority of magnesium oxysulfate over magnesium oxychloride. Redeker found that when tested under the same fire conditions, the neet mix of magnesium oxychloride began to significantly decompose between 371 and 538°C (700 and 1000°F), while the comparable neet magnesium oxysulfate mix decomposed between 900 and 1093°C (1650 and 2000°F). In other words, it took more than twice the temperature to decompose the oxysulfate to a comparable degree as it took to decompose the oxychloride.

This is shown in Tables 1 and 2 extracted from Redeker's extensive research on oxychlorides and oxysulfates.

Conclusion

Both magnesium oxychloride cements and magnesium oxysulfate cements are excellent products for use as spray applied fire resistive coatings. They have certain unique properties that have made possible their use in developing penetration seals that were awarded a 3-h fire rating by the Nuclear Energy Liability Property Insurance Association (NEL-PIA)[4] after passing rigorous fire testing at the Studsvik Laboratories in Sweden [*9*]. These unique properties have also been usd to develop mine sealants in cooperation with the U. S. Bureau of Mines [*10*] that are accepted by the Mine Safety Health

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[3] Redeker, C. W., "The Thermal Decomposition of Magnesium Oxychloride and Magnesium Oxysulfate Cement," private correspondence, 1967.

[4] Nuclear Energy Liability Property Insurance Association, letter of approval, 1977.

Administration (MSHA)[5] as fire barriers and strata protection in coal mines, and by the U.S. Bureau of Mines [*11*] and MSHA as ventilation control and radon gas barriers in uranium mines and other hard rock mines.

In most cases both magnesium oxychloride and magnesium oxysulfate cements would do an equally good job, however, for the reasons previously stated, for spray applied fire resistive coatings, magnesium oxysulfate cements are best suited.

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[*9*] "Fire Endurance Test on Penetration Seals Systems and Cables," Studsvik, AB Atomergi Sweden, 1977.

[*10*] Fraley, J. E. and Simpson, R. E., "Coal Mine Sealants," U.S. Bureau of Mines, Spokane, Wash., 1974.

[*11*] Franklin, J. C. and Muslim, C. S., U.S. Bureau of Mines, and Thebeau, D. W., "Research on Bulkheads for Radon Control in Mines," presented at the second conference, Uranium Mining Technology, Exxon Corporation, Spokane, Wash., 1978.

DISCUSSION

Written Discussion

F. M. Stumpf[1]—Given the same exact conditions for magnesium oxychloride and magnesium oxysulfate fire resistive materials applied to steel, will there be a difference in corrosion?

M. E. Herrera (*author's response*)—Given the same exact conditions, ambient temperature, humidity, setting time, cement slump and so forth, during the application to steel of magnesium oxychloride and magnesium oxysulfate fire resistive materials, one can expect the following.

The magnesium oxychloride will clearly show "flash rusting" before setting since the chloride ion is very active until it reacts with the magnesium oxide to form the cement. Furthermore, if both cements are regularly exposed to

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[5] Mine Safety Health Administration, letter of acceptance, 1978.

[1] U.S. Mineral Products Company, Stanhope, N. J. 07874.

high humidity or damp conditions, the magnesium oxychloride mix will show moderate to heavy corrosion build up. The oxysulfate will show only minor amounts. The addition of minor amounts of chromates to oxychloride mixes helps to reduce the initial flash rusting, but it has very little effect on long-term corrosion.

Recorded Discussion

Frank M. Stumpf—Conditions of the material applied to steel, do you find one superior to the others?

M. E. Herrera—Yes, the oxysulfate would be superior. This was shown very clearly when the people that were in charge of the specifications for the Queen Mary ran some very rigorous testing. We had two products that we could supply, one was a magnesium oxychloride base, and one was a magnesium oxysulfate base, and in less than three days in a wet chamber they decided they could not use the oxychloride because obviously the Queen Mary is in the bay, where there is a high humidity factor. In addition, the oxysulfate never did corrode during the test period.

Morris Lieff[1]

Fire Resistive Coatings in the USSR: An Overview

REFERENCE: Lieff, M., "**Fire Resistive Coatings in the USSR: An Overview,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826*, Morris Lieff, Ed., American Society for Testing and Materials, 1983, pp. 102–114.

ABSTRACT: The use of fire resistive coatings in wood and steel construction is reviewed by the author, who visited the Union of Soviet Socialist Republics (USSR) in July 1981, as a member of the US-USSR Panel on Fire Protection. Included are English translations of two Soviet standards (GOST) for Fire Protective Phosphate Coatings for Wood and for Steel.

KEY WORDS: intumescent coating, phosphate coating, wood, steel, GOST standards, fire resistive coatings

As part of the bilateral United States–United Soviet Socialist Republic (US–USSR) agreement to cooperate in "The Field of Housing and Other Construction" there is a panel on "Fire Resistance of Buildings and Structures." The parent agreement is administered by the Department of Housing and Urban Development (HUD). The American cochairman of the panel on fire protection is Dr. Robert Levine, Chief, Fire Research Resources Division, Center for Fire Research, National Bureau of Standards.

An American mission first visited the USSR in Dec. 1977. The Soviet side visited the United States in the summer of 1979. The second visit of the US–USSR panel on Fire Protection to the USSR took place in July 1981. The members of the American mission were:

Dr. Robert Levine, National Bureau of Standards, Chairman,
Dr. R. Friedman, V.P., Factory Mutual Research,
Dr. Henri Mitler, Harvard University,
Dr. Boris Kuvshinoff, Johns Hopkins University,
Dr. Morris Lieff, County College of Morris, and
Dr. J. B. Thompson, FEMA (formerly of National Fire Academy).

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[1] Division dean, Science, Technology, and Mathematics, County College of Morris, Dover, N. J. 07869.

The return visit of the USSR team of experts was scheduled for the week of the ASTM symposium, Fire Resistive Coatings: The Need for Standards, and attending this symposium was part of their 1982 agenda. Unfortunately, illness of two members of their delegation necessitated postponement of their visit.

Background

The Soviets have a strong interest and give strong emphasis to their work on fire resistive coatings. In reviewing the development and use of fire protective coatings in the USSR, it may be useful for the American reader to have an understanding of the nature of the organizational structure within which the fire protection engineer works. Thus a brief comparison of the American and USSR systems is presented from the viewpoint of one involved with fire resistant coatings.

In the United States fire resistive coatings are of a proprietary nature, and there are many on the market. They are used primarily when they are required by various building codes and government regulatory agents. To meet these regulations, coatings developed by various manufacturing interests must be tested by an institution such as Underwriters Laboratories, Inc. (ULI), or Factory Mutual Research, in accordance with ASTM Fire Tests of Building Construction and Materials (E 119-81) or ASTM Test for Surface Burning Characteristics of Building Materials (E 84-81a), and are published annually in the UL Fire Resistance Directory or Factory Mutual System Approval Guide. Specification and use of approved products are determined by architects, contractors, or owners of the structure involved.

Standards Development in the USSR

In the USSR the system is completely centralized in two ministries. At the focus is Gosstroy, the Ministry of Construction, and the Ministry of Interior. Gosstroy's job is technical preparation of standards and norms[2] for buildings, structures, and their erection. Norms for fire resistance, safety, sanitation, and so forth are worked out for the Soviet Union as a whole and can be augmented by local norms. Each republic of the Soviet Union has its own Gosstroy and adds something to the national codes depending on local conditions and local traditions of decorations. Gosstroy is responsible for norms for residential buildings, agricultural structures, and industrial plants. On fire protection Gosstroy cooperates with the Ministry of Interior, which includes the Department of Fire Protection. Norms for fire resistance are developed by Gosstroy but approved only after consultation with the Department of Fire Protection. Before construction projects are finalized, they are

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[2] In the Soviet sense a norm states what "should" be, whereas a standard specifies what "must" be.

coordinated with the local fire protection agencies. The local office of the Ministry of Interior sees that the contractors comply with the norms generated by Gosstroy during construction. After the building is completed, a special commission checks the building for compliance with fire protection and other codes, and the building is repaired if the work is not up to standard. The fire inspection department thereafter looks at the building at least twice a year.

Research and development of various structures are conducted in various institutes. Four important institutes are:

(1) All-Union Research Institute for Fire Protection (VNIIPO),
(2) Kutsherenko Central Research Institute for Building Structures (CNIISK),
(3) Central Research and Design Institute for Industrial Buildings (CNIIPZ), and
(4) Research Institute for Concrete and Reinforced Concrete (NJIZB).

There are many research institutions, but these four are the central ones and coordinate the others.

The main task of the central institutes is to develop new norms and document product development. Development of coatings, norms, and standards for their use are elaborated in these institutes.

USSR Norms for Fire Protection Requirements

Based on a meeting in which a discussion of fire protective coatings was held with representatives of several of the Soviet institutes, CNIISK, VNIIPO, and NJIZB, the following information was developed.

Norms for protection of metal structures in the USSR range from 15 min to 2 ½ h. It is assumed that unprotected steel has a rating of 15 min. There is wide use of very thin-walled metal structures, including aluminum. From the point of the state economy, structural elements are designed (by computer) to minimize the quantity of metal needed. Some elements have been reduced down to 2 mm in structures, such as space grids and shells. The fire endurance of such structures is very limited and is less than 15 min.

The criteria used in evaluating the fire endurance are (1) temperature of the structure, (2) developments of openings and cracks, and, (3) structural failure during fire exposure.

The norms that have been developed are valid for building heights up to 16 stories. For structures greater than 16 stories special fire resistance requirements are determined.

Type of Protection Used in the USSR

How should building structures be protected? Classical methods now being used are (1) concrete and brickwork and (2) plaster on expanded metal base with density of 600 to 2500 kg/m^3 (37 to 55 lb/ft^3). These are manual methods. High-rise load bearing columns require 3- to 4-h endurance and are usually concrete.

Attention has been directed to lightweight material for fire protection, namely, (1) sprayed method and (2) covering plates. The method to be used is determined case by case, whichever is most economical.

In the field of coatings, designated phosphate coatings, many formulations have been proposed (about ten). The most widely used are of two compositions (see Appendix).

1. The first is composed of water glass (sodium silicate solution), asbestos, and a hardening agent (orthophosphoric acid). A state standard or GOST is now available. This document describes the two layers, volumetric mass, density, strength, components, requirements for quality control and manufacturing, as well as how to spray and what technological parameters are to be maintained. Special high-capacity equipment is used for its application.

   The negative features of this type of coating are (1) it contains asbestos (research is now directed to eliminate the asbestos by providing a substitute), (2) it is not suitable for exterior use or in very high humidity, and (3) it is necessary to make the coating waterproof.

2. The second composition is an intumescent type, which is more like a paint and may contain as many as ten organic components. It is applied in three layers. The first layer, which has a dry thickness of 1 mm, provides a suitable substrate for adhesion to the metal. The top layer protects the intumescent layer from water, abrasion, or other wear. The final thickness is approximately 4 mm ($^5/_{32}$ in.). When heated, it expands approximately ten times or more and provides 0.75-h protection on metal structures. It is applied in the form of a water suspension at a rate of 5 to 6 kg/m^2 (1 to 1.2 lb/ft^2) and has a final dry density of approximately 1000 kg/m^3 (60 lb/ft^3). This product is designated VPM-2. Its drawback is that it is not water resistant. The standard for this product is now under development and is expected to be approved by Gosstroy at the end of 1981.

Because coatings will sometimes flake or drop off, close inspection of the application is required. To ensure proper application, special guidance instructions for application to metal constructions were published in 1982. They contain recommendations on technology, chemistry, practical applications, and the date of recommendation.

Critical temperatures of metal during fire exposure are dependent on the load and the geometry of the structure. For a low carbon steel beam the critical temperature is 450 to 550°C. For thin membranes used in suspended roof systems (as in the sports palaces) the critical temperature is 800 to 900°C at which time sagging occurs. However, the perimeter ring must be highly protected.

VPM-2 can be used to protect aluminum structures. There is no corrosion of the metal, and it is suitable for application up to 80% relative humidity. VPM-3 suitable for 100% relative humidity is being developed.

At the conclusion of this meeting, we were handed the following USSR State Standards dealing with spray-applied phosphate insulating materials for increasing fire resistance of steel and wood structures. These are:

(1) Fire Protective Phosphate Coating for Steel (GOST 23791-79) and
(2) Fire Protective Phosphate Coating for Wood (GOST 23790-79).

The English translations of these two standard are contained in the appendix.

In discussions with CNIISK specialists, it was indicated that their product had been licensed in France, Australia, Hungary, Germany, and Japan and had been widely used on structures built for the 1980 Olympics.

The USSR representatives indicated that their phosphate coatings have been improved so that they will compete satisfactorily with American products in international markets.

Summary

The organizational structure, standards development, and norms for fire protection requirements of structures in the USSR are reviewed. Types of protection and in particular phosphate coatings are discussed. English translations of USSR State Standards dealing with phosphate fire protective coatings for steel and wood are provided.

As a final comment I would like to indicate that this trip has put into sharp focus the need to gather and centralize information. We would like to learn more about USSR phosphate coatings and in particular to review and document our American technology.

Acknowledgments

The author gratefully acknowledges the assistance of Boris Kuvshinoff and Boris Guberman in translating the GOST standards into English and the help of Dr. Robert Levine in preparation of the manuscript.

APPENDIX

USSR State Standard GOST 23791-79

The following is an English translation of the USSR State Standard Fire Protective Phosphate Coating for Steel (GOST 23791-79). GOST 23791-79 was approved 27 July 1979 by the USSR State Committee on Building Affairs (Gosstroy–USSR) and became effective 1 Jan. 1980.

Violation of Standard Will be Prosecuted

The present standard deals with fire protective phosphate coating for steel that is applied either in the plant or on the construction site onto steel structures to increase the limits of their fire resistance.

TABLE 1—*Thickness of the coating layer.*

Thickness of Fire Protection Coating, mm	Minimum Fire Resistance Limit of Construction, h
10	0.5
20	1.0
30	1.5
40	2.0
50	3.0

This standard stipulates the main requirements for coating, components needed for its preparation, as well as the technology of its application.

1. Requirements for Coating

1.1 The coating should be used for fire protection of interior steel structures with average environmental relative humidity not exceeding 75%.

1.2 The coating should be applied in one layer in accordance with the requirements stipulated in the mandatory index. It is permissable to finish the coating by either varnishing or painting the structure.

1.3 The fire resistance limit of the fire protection of the steel construction is determined by the thickness of the coating layer in accordance with Table 1.

1.4 The limit of the variation in thickness of the applicable layer should not exceed ±5%.

1.5 The coating shall be free of cracks, separation, and swellings.

1.6 The basic physical-mechanical properties of the coating should correspond to Table 2.

1.7 Precoated structures should be transported in accordance with requirements of SNiP on management of construction.

1.8 After being coated the structure should be stored in dry rooms.

1.9 During transportation and storage, relative humidities exceeding 75% may cause hydrolysis of the surface of the structure (see Part 3.7).

1.10 Coating consists of the following components: asbestos, water glass, and nepheline fire retardant.

1.11 Components used for 1-m^3 coating allowing for 10% production loss are shown in Table 3.

1.12 Coating component chrysotile asbestos Grade 111-V semirigid morrocan in accordance with Parts 3-50, 3-70, 5-50, and 5-65 of GOST 12871-67.

1.13 Coating component—potassium silicate ratio 2.6 to 2.8 in accordance with officially approved normative documentation or sodium silicate ratio 2.6 to 2.8 in accordance with GOST 13078-67.

TABLE 2—*Basic physical-mechanical properties of the coating.*

Physical Property	Norm
Density, kg/m^3 maximum (lb/ft^3)	300 (18.7)
Ultimate compressive strength, kgf/cm^2 minimum (lb/in.^{2})	5.0 (70.0)

TABLE 3—*Components used for 1-m^3 coating allowing for 10% production loss.*

Name of Components	Amount, kg/m^3 (lb/ft^3)
Asbestos	159 (10)
Water glass, (sodium silicate solution) density = 1.2 g/cm^3	120 (7.5)
Nepheline fire retardant	21 (1.3)

1.14 Coating component—Nepheline fire retardant ground to fine powdered condition in accordance with officially approved normative-technical documentation. The residue on a No. 018 screen in accordance with GOST 3584-73, should be no greater than 7%.

1.15 Coating components should be supplied in metal drums, polyester, or paper bags and stored in accordance with requirements of officially approved normative-technical documentation.

2. *Quality Control of Coating*

2.1 The completed application of coating should be checked for correspondence with requirements of the present standard and should be accepted by the department for technical control of the plant/manufacturer of the structures. When applying the coating on the construction site, acceptance of the prepared coating is carried out by the user and will be confirmed by informal certification.

2.2 Acceptance of the coating will be carried out when a unit area is completed. A unit area is considered to be not more than 1000 m^2 (10.750 ft^2) of protected surface of metal structures.

2.3 When accepting the unit area, the external state of the coating and its thickness, density, and ultimate compressive strength must be inspected.

2.4 Each structure and the external state of the coating must be inspected (Part 1.5).

2.5 If during inspection of the external state of the coating, it is found that more than 10% of the structure per unit area does not meet the requirements of Part 1.5, the whole unit area will not be accepted.

2.6 Not less than five structures from each unit area will be inspected. Measurement is by means of a vernier caliper in accordance with GOST 166-73. The value will be the average of five measurements.

2.7 Determine the ultimate compressive strength and density of the coating in accordance with GOST 17177-71. For determining ultimate compressive strength and density of the coating, select specimens of three constructions from each unit. The value shall be the average of three measurements.

2.8 Should the results of a single value not be in accordance with Parts 1.4 and 1.6, the whole unit area will be rejected.

Mandatory Appendix: Preparation and Application of Coating Composition

1. *Materials*

1.1 Materials to be used for coating shall meet the requirements of Parts 1.12 through 1.14 of this standard.

2. *Preparation of Coating Composition*

2.1 Preparation of dry mixture. Asbestos and nepheline fire retardant are weighed on the weighing batchers with an accuracy of ±1% and are mixed in continuous mixers. The time of mixing is not less than 5 min.

2.2 Water glass is diluted with hot water with a temperature no higher than 80°C and is mixed continuously for not less than 3 min until a density $\rho = 1.2$ g/cm^2 (specific gravity, Part 1.2) is obtained.

It is permissible to dilute water glass with cold water with a temperature of 20 ± 5°C, increasing the mixing time to 10 min. The diluted water glass is filtered through a No. 05 screen of GOST 3584-73.

2.3 The dry mixture and water glass are loaded and mixed with air.

3. Application of Coating Composition

3.1 Application of the coating composition may be carried out in the plant of the fabricator of the steel construction or with special organization directly on the job site.

3.2 The coating is applied on the steel construction after coating with a red-lead steel primer in accordance with GOST 8135-74 or with Type GF primers in accordance with GOST 4056-63 or GOST 12707-77, and in accordance with the requirements of SNiP for protection of steel construction against corrosion.

3.3 The surface of the construction is wet with water glass, density 1.02 g/cm^3 (specific gravity 1.2). Then the composition (dry mixture and water glass) is applied to the necessary thickness with the spraying equipment.

Pressure of compressed air, 3 kg/cm^2 (43 lb/in.^{2})
Pressure of water glass at outlet, 2.5 kg/cm^2 (36 lb/in.^{2})
Distance of sprayer to surface to be protected when jet is directed upwards, not more than 500 mm (20 in.)
Distance of sprayer to surface to be protected when jet is directed either horizontally or downward, not more than 700 mm (28 in.)

The distance can be reduced in restricted areas to 200 mm (8 in.).

3.4 It is necessary to follow the requirements of SNiP for finishing coating of steel constructions when applying the coating composition.

3.5 Ambient air temperature should not be less than 5°C, relative humidity of air not more than 75%, and coating composition should not be applied during rain or snow.

3.6 Drying of coating should be done under natural conditions with air temperature not less than 5°C and humidity greater than 75% for 48 h. Drying with temperatures of 80 to 100°C in less than 5 h is permissible.

3.7 Either pentaphthalein enamel PF-115 according to GOST 6465-76 or chemical resistant enamel XC-534 according to TU 6-10-801-76 can be applied on the dry coating as protection from moisture or as decorative finish in two layers with the aid of a spray gun according to GOST 7385-73 with a maximum compressed air pressure of 5 kg/cm^2 (72 lb/in.^{2}).

It is permissible to apply the enamel by roller in two layers according to GOST 10831-72.

Application and drying of this type of enamel shall be done according to normal-technical documentation that has been approved in the appropriate manner.

3.8 Coating that is damaged during application, transportation, or installation should be repaired in accordance with requirements of this standard.

4. Methods of Control

4.1 Moisture content of the asbestos, density of the water glass, fineness of the grind of the fire retardant, and data of application (pressure of compressed air, pressure of water glass at sprayer outlet, and distance from sprayer to surface being protected).

4.2 Moisture content of asbestos is specified by GOST 17177-71.

4.3 Density of water glass specified with hydrometer by GOST 1300-74.

4.4 Fineness of grind is specified by GOST 3102-76.

4.5 Pressure of compressed air and pressure of water glass are controlled with a gage, according to GOST 8625-77.

5. Safety

5.1 Working places should be equipped with forced air ventilation.

5.2 Workers who apply the coating should be provided with personal protective devices: rubber gloves, respirators, protective goggles, and coveralls.

USSR State Standard GOST 23790-79

The following is an English translation of USSR State Standard Fire Protective Coating for Wood (GOST 23790-79). GOST 23790-79 was approved 27 July 1979 by the USSR State Committee on Building Affairs (Gosstroy–USSR) and became effective 1 Jan. 1980.

Violation of Standard Will be Prosecuted

The present standard deals with fire protective phosphate coating for wood that is applied either in the plant or on the construction site onto structures made of wood or wood-containing products. Structures with such a coating refer to the category of low-combustible materials corresponding to GOST 16363-76. This standard stipulates the main requirements for coating, components needed for its preparation, as well as the technology of its application.

1. Requirements for Coating

1.1 The coating should be used for fire protection of interior structures with relative humidity not exceeding 75%. The application of the coating under conditions of higher relative humidity is permissible provided that a water resistant insulating layer is applied after the coating has dried.

1.2 It is permissible before application of the coating to treat the structure with water soluble preservatives and after application of the coating, the structure may be varnished.

1.3 The coating must consist of two or three layers applied in accordance with the requirements stipulated in the mandatory appendix.

1.4 The thickness of the coating shall be 0.6 to 0.8 mm (0.02 to 0.03 in.). The normal coverage of the dry mixture with due account for production losses will be 500 to 700 g/m^2 (0.1 to 0.14 lb/ft^2) of coating.

1.5 The coating shall be free of cracks and separations, and should be uniformly applied. Uneveness of the coating caused by spots thicker than 1.5 mm (0.06 in.) should not be present. The number of these thickened areas of 1.5 mm (0.06 in.) thickness will not exceed 5/m^2 (0.5/ft^2).

1.6 The surface of the coating should not be exposed to mechanical abrasion. In case of surface damage during erection or transportation, all damaged areas will be recoated in accordance with Part 3 of the mandatory appendix.

1.7 After being recoated the structures should be stored in rooms with relative humidity no greater than 75%.

1.8 Precoated structures should be transported in accordance with requirements of SNiP on management of construction.

1.9 The coating consists of the following components: filler, phosphate binder, flame retardant, and pigment.

1.10 As filler, use kaolin or clay containing (by weight) not less than 30% alumina, not less than 40% silica, and use fly ash from thermal power stations containing not less than 40% silica and not less than 15% alumina.

1.11 As the binder use sodium polymetaphosphate, technical grade according to GOST 20291-74.

1.12 As flame retardant use aluminum hydroxide in accordance with officially approved normative-technical documentation and technical grade urea according to GOST 6691-77 or thiourea according to GOST 6344-73.

1.13 As pigment use ferric oxide powder according to GOST 8135-74 or technical zinc oxide according to GOST 10262-76.

1.14 The moisture content of components should not exceed 2% by weight.

1.15 The components should be supplied in polyethylene containers, kraft paper bags, or plywood and metal drums and should be stored in dry rooms.

1.16 The composition of the dry coating mixture (without consideration of losses during manufacture) should correspond to the Table 4.

2. *Quality Control of Coating*

2.1 The completed application of coating should be checked for correspondence with requirements of the present standard and should be accepted by the department for technical control of the plant/manufacturer of the structures. When applying the coating on the construction site, acceptance of the prepared coating is carried out by the user and will be confirmed by informal certification.

2.2 Acceptance of the coating will be carried out when a unit area is completed. A unit area is considered to be not more than 2000 m^2 (21 500 ft^2) of protected surface of timber structures.

2.3 When accepting the unit area, the external state of the coating and its thickness must be inspected.

2.4 Each structure and the external state of the coating must be inspected (Part 1.5).

2.5 If during inspection of the external state of the coating, it is found that more than 10% of the structure per unit area does not meet requirements of Part 1.5 the whole unit area shall not be accepted.

2.6 Not less than ten structures from each unit area will be inspected by means of a caliper (or micrometer) of ±0.1 mm accuracy according to GOST 166-73.

2.7 The value shall be the average of ten measurements. Should the results of the inspection be unsatisfactory the whole unit area will be rejected.

TABLE 4—*Composition of dry coating mixtures.*

Name of Component	Normal Amount Used, Percent by Weight
Sodium polymetaphosphate	35 to 40
Aluminum hydroxide	14 to 16
Kaolin (clay)[a]	4 to 6
Fly ash	14 to 16
Ferric oxide (zinc oxide)	4 to 6
Urea (thiourea)[b]	18 to 22

[a] Within the parenthesis are given the names of alternate materials.

[b] When using urea store in separate containers, do not permit mixing with other components of the dry mixture.

Mandatory Appendix: Preparation and Application of Coating Composition

1. Materials

1.1 Materials to be used for the preparation of the dry materials will meet the requirements of Parts 1.10 through 1.14 of this standard.

2. Preparation of Coating Composition

2.1 Preparation of coating composition shall consist of (1) preparation of the dry mixture and (2) preparation of the slurry.

2.2 Preparation of the dry mixture.

2.2.1 The dry mixture is prepared in the appropriate manner under manufacturing conditions. When the job size is small, it is permissible to prepare the dry mixture on the construction site; if so, protection of components and equipment from humidity and foreign matter should be provided.

2.2.2 Mixture components with moisture content greater than 2% by weight shall be dried at a temperature of not more than 100 ± 10°C in any drying equipment (drying cabinet, furnace, and drum).

2.2.3 Sodium polymetaphosphate, clay, and thiourea shall be ground in a grinder up to particle size of not more than 15 mm (0.6 in.).

2.2.4 Proportioning of components is carried out by means of a weight proportioner with an error of not more than 0.1% by weight.

2.2.5 Mixing and grinding of components is carried out in a ball mill with porcelain bodies to a grain fineness so that no more than 2% by weight is retained on a No. 018 screen according to GOST 3584-73.

2.2.6 Unit weight—the weight of the dry mixture in compacted condition shall not exceed 215 kg/m^3 (13.5 lb/ft^3).

2.2.7 The dry mixture should be stored in polyethylene containers, kraft paper bags, or plywood and metal drums for not more than one year in dry rooms.

2.3 Preparation of slurry.

2.3.1 Slurry preparation is carried out in a paddle mixing apparatus in batch process. It is permissible to carry out the mixing in metal tanks.

2.3.2 Sequence of slurry preparation—into an empty tank, pour the required quantity of water heated to 20 to 70°C, add the dry mix, and mix to homogeneous consistency. When using urea, it must be previously dissolved in water and the remainder of the dry mix added to the urea solution.

2.3.3 The composition of the slurry should correspond to that given in Table 5.

2.3.4 Viscosity of slurry should not exceed 20 c according to viscosimeter B2-4 for application of the coating by means of pneumatic spraying and not more than 40 c by hand application or by pouring.

2.3.5 The prepared slurry is filtered through a screen in accordance with GOST 3584-73, having openings of not more than 1 mm. Should the residue on the screen exceed 2% by weight, the mixing should be repeated.

2.3.6 The wet mix can be stored in hermetically sealed closed containers in a dry room at temperatures not less than 5°C for more than six months, without loss of its properties. In the case of thickening the wet mix shall be thinned with water of temperature 20 to 70°C, to required viscosity.

3. Application of Coating Composition

3.1 The surface of the construction before coating should be cleaned completely of grease spots, organic paint spots, and contamination, by means of subsequent blowing with compressed air.

TABLE 5—*Composition of slurry.*

Description of Components	Quantity of (parts by weight)
Dry mixture (with thiourea)	5
Water (from water tap)	4

NOTE—When using urea, dry mixture (without urea) is four parts by weight and one part of urea.

3.2 The coating should be applied to a construction that has no more than 16% moisture by weight.

3.3 Application of the composition.

3.3.1 The coating is applied in three layers by an air gun driven by a Type burner (BNR) pump in accordance with a normative technical documentation that has been approved in the appropriate manner, or a paint spray gun according to GOST 7385-73 with air pressure up to 5 kg/cm^2 (72 lb/in.^{2}). When using the paint spray gun, the distance between the nozzle of the gun and the surface of the construction during application of the coating should not be greater than 40 cm (15 in.), and when using the BNR pump, apply the coating at a distance of not more than 70 cm (27.5 in.). The coating may be applied by hand in two layers with a paint brush according to GOST 10597-70 or by a roller according to GOST 10831-72.

3.3.2 Each freshly applied layer of the coating should be dried at a temperature not greater than 50°C until all traces of moisture have disappeared. The coating may be dried under natural conditions when the ambient air temperature is not less than 10°C. Drying time at 50°C is 2 h and under natural conditions 24 h.

3.3.3 To protect the coated construction from moisture in places having relative humidity above 75% or in the case of a decorative finish, the coating should be protected by pentaphtalein enamel PF-115 according to GOST 6465-76 or enamel XC-534 according to TU 6-10-801-76.

3.3.4 Pentaphthalein or XC enamels are applied on the dry coating in two layers with the aid of a paint spray gun according to GOST 7385-73, by a paint brush according to GOST 10597-70, or by a roller according to GOST 10831-72.

4. *Methods of Control*

4.1 The mass of the dry mixture in compacted state is determined according to GOST 21119.6-75.

4.2 The fineness of the grind of the dry compound is determined according to GOST 310.2-76.

4.3 The moisture content of wood constructions is determined according to GOST 16588-71. The average value of ten measurements is taken as the result.

4.4 The moisture content of the dry components of the mixture is measured according to GOST 5382-73.

4.5 Dry material specimens are selected according to GOST 9179-77.

4.6 The viscosity of the slurry is determined by GOST 8420-74. Specimen selection is according to GOST 5802-78.

5. *Safety*

5.1 Premises in which dry compound is being prepared should be equipped with forced air ventilation.

5.2 Protective goggles, a respirator, a rubber suit, and gloves should be worn during the preparation of the slurry and its application.

5.3 If the slurry should contact the skin, the material should be removed with cotton or tissue and then washed with soap and water.

DISCUSSION

Ken Zacharias[1] (*written discussion*)—Based on your discussions with the Russians, can you tell me why they do not regard the use of asbestos as a health hazard?

Morris Lieff (*author's closure*)—Although the Soviet representative indicated that the use of asbestos in the coating did not present a health problem at this time, it is clear to me that they consider it a potential health hazard since they are conducting research on finding a suitable substitute and hope to eliminate asbestos from their formulations. The coatings have not been in use long enough to develop any statistics on health hazards.

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[1] National Paint and Coating Association, Washington, D.C. 20005.

Peter L. Berry[1]

Surface Preparation of Steel for Fire Resistive Coatings

REFERENCE: Berry, P. L., "**Surface Preparation of Steel for Fire Resistive Coatings,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 115–125.

ABSTRACT: The preparation of steel substrates to receive fire resistive coatings has not been formally investigated. The types and conditions of steel surfaces are analyzed from a climatic, physical, and chemical point of view, and recommendations for each condition are made.

KEY WORDS: fire resistive coatings, insulation, primers saponification, temperature gradients, surface preparation

This paper discusses the problem of the preparation and acceptance of steel surfaces to receive fire resistive coatings. Very little formal research has been conducted on this topic. As a user of various fire protection materials, I felt the need to systematically compile the current published background information as it relates to the problems the user can run into, which defines areas where research attention should be focussed.

The conditions to be addressed are as follows:

(1) freezing surfaces/moisture/ventilation,
(2) galvanized surfaces,
(3) oily surfaces,
(4) painted surfaces, and
(5) rust/mill scale.

The fire protection products being considered typically have a gypsum or portland cement base, lightweight aggregate, such as vermiculite or mineral wool, and a substantial water to solids ratio at the time of application.

It should be noted that the vast majority of steel surfaces raise no problems for the fire protection applicator; however, all parties should be aware of potential problems, and the onus has to be on the steel supplier to provide an acceptable substrate for the sprayed fire protection.

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Freezing Surfaces/Moisture/Ventilation

The critical temperature for the free movement of capillary water being 0°C (32°F), most manufacturers require that the atmosphere and substrate be maintained above 4°C (40°F). This is done typically by compartmenting the area being sprayed with hoarding, or with exterior cladding, and using temporary heat.

No problems are encountered as long as the substrate metal deck is maintained at a temperature above 0°C (32°F). Difficulties occur, however, in maintaining the temperature of the protected metal deck during the curing period.

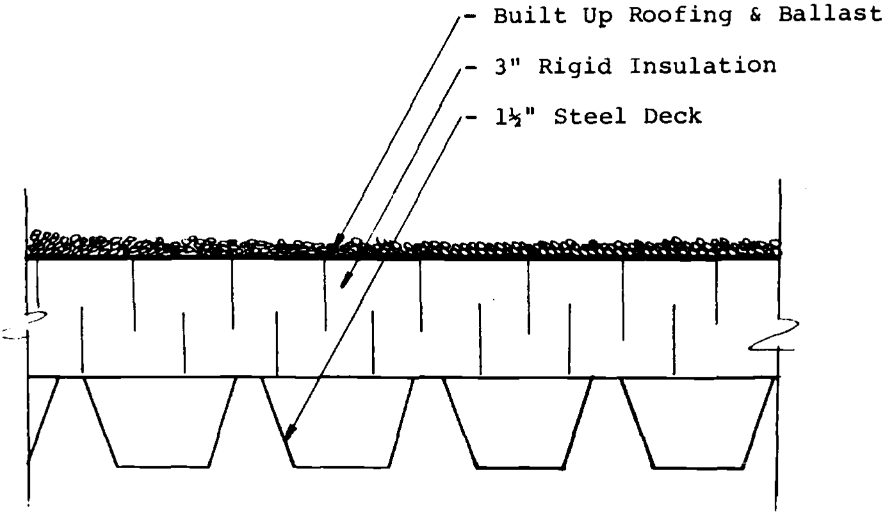
Some of the factors that influence the deck temperature are:

(1) Night sky radiative cooling in accordance with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard for Infra-red Detection of Heat Losses from Buildings (SPC 101),
(2) outside temperature,
(3) temperature gradient across the slab or roof insulation,
(4) accumulation of moisture at the deck/fire protection interface,
(5) any chemical reaction/phase change in the fire protection material after application,
(6) insulation value to the deck by the fire protection material, and
(7) compartment temperature and humidity.

Based on Conditions 2, 3, and 7, the only variables, the following examples of temperature gradients across the concrete floor slab or roof insulation material give a basic idea of when it is necessary for control of the interface temperature to either

(1) cease spraying and wait for warmer climatic conditions,
(2) increase interior heating,
(3) heat the compartment above the one being sprayed, or
(4) lay insulating blankets on the floor above while heating the compartment below (Figs. 1 and 3).

The following specific temperature gradients do not take account of solar input during the day and the "night sky radiative cooling effect" at night, (Figs. 2 and 4). On a still clear night the "night sky effect" can cause up to a 11.2°C (20°F) temperature drop of the substrate below air temperature. This phenomena has been documented and is a reason behind frost warnings when the air temperature is at 4.4°C (40°F).



COMPONENTS	'R' VALUE
1½" Steel Deck	0
3" Rigid Insulation	12.0
Built Up Roofing & Ballast	0

FIG. 1—*Typical roof assembly.*

Example of Simplified Thermal Gradient Calculation

Stainton uses the formula [*1*]

$$\Delta_{Tas}/\Delta_{Taa} = \Delta_{Ras}/\Delta_{Raa}$$

to show the relationship between

Δ_{Tas} = temperature change from inside air to substrate,
Δ_{Taa} = temperature change from inside air to outside air,
Δ_{Ras} = R value change from inside air to substrate, and
Δ_{Raa} = R value change from inside air to outside air.

If the uncured sprayed fireproofing is assumed to have an R of 0.5 then with a roof assembly with 76.2 mm (3 in.) of insulation (R12)

$\Delta_{Ras} = R$ inside film $\neq 0.5 = 0.68 \neq 0.5 = 1.18$,
$\Delta_{Raa} = 1.18 \neq 12 = 13.18$,
$\Delta_{Taa} = 40 \neq 15 = 55$ (assuming inside temperature 4.4°C (40°F), outside −25°C [−15°F], and
$\Delta_{Tas} = (55 \times 1.18)/13.18 = 4.92$.

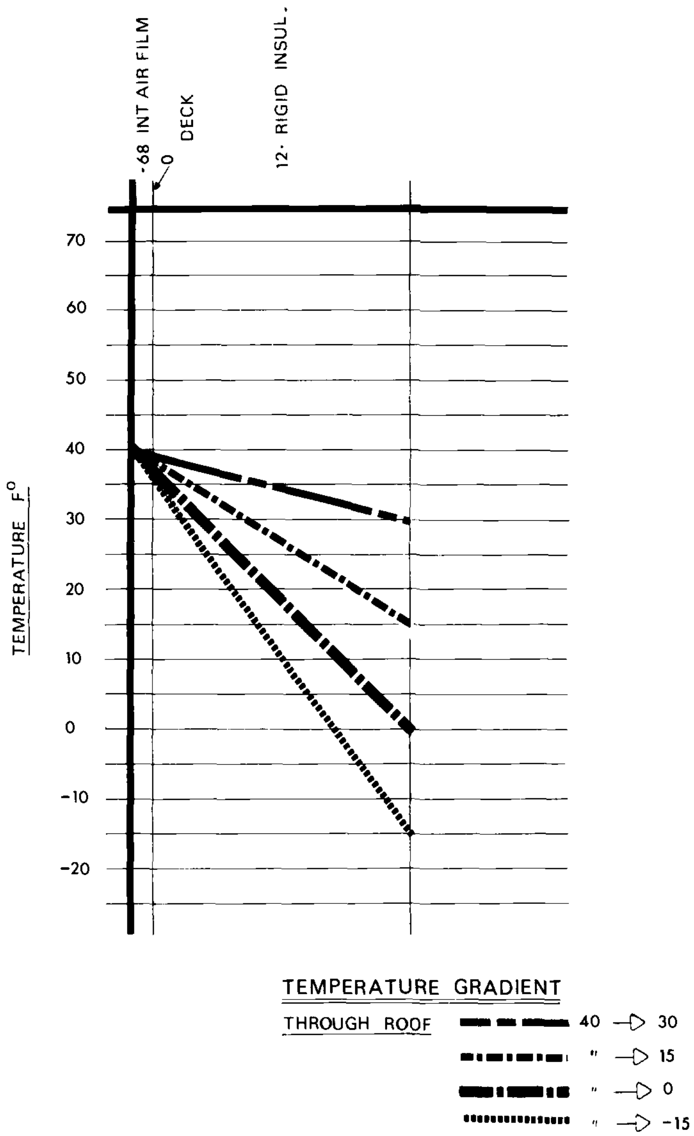
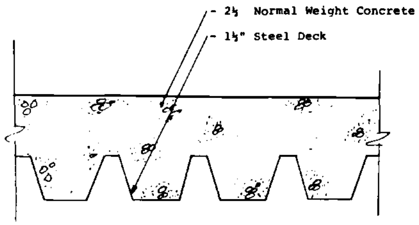


FIG. 2—*Temperature gradients.*

Thus under the above conditions, the approximate temperature drop from inside air to substrate would be 2.77°C (4.9°F).

Conclusions (Ignoring "Night Sky Effect")

With an outside temperature of −25°C (−15°F) and 76.2 mm (3 in.) of fiberglass insulation on a roof, there is no problem maintaining the substrate above freezing.



COMPONENTS	'R' VALUE
1½" Steel Deck	0
2½" Normal Weight Concrete	.20

FIG. 3—*Typical floor assembly.*

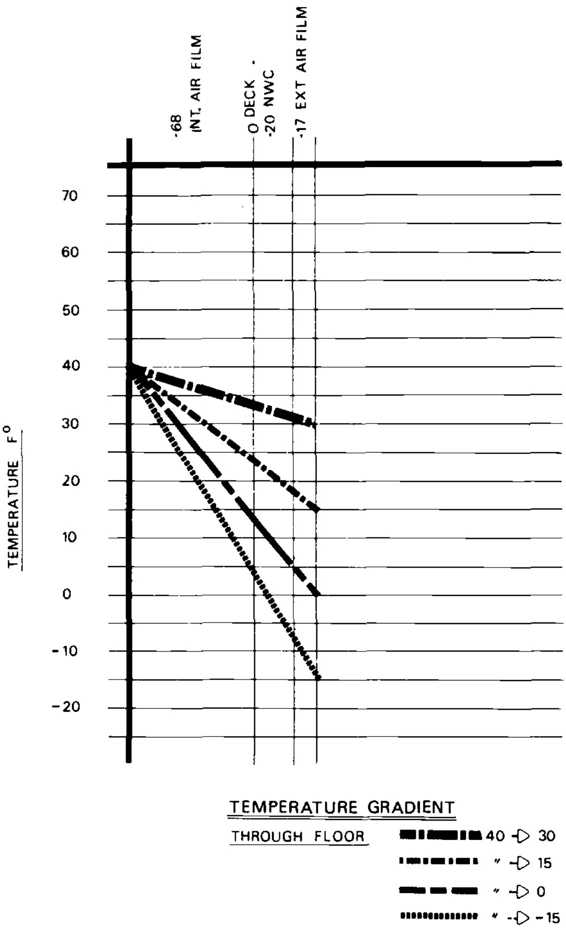


FIG. 4—*Temperature gradient for floor assembly.*

With an outside temperature of −25°C (−15°F) and 25.4 mm (1 in.) of fiberglass insulation on a roof, it is too risky to spray fireproofing.

With an outside temperature of −25°C (−15°F), it is risky spraying a floor with 63.5 m (2 ½ in.) of normal weight concrete unless the floor is insulated or the floor above is heated.

The typical result of the substrate falling below 0°C (32°F) is a falloff at some later date when the substrate warms. With vapor/moisture migrating to the cold surface and the deck acting as a vapor barrier, the subsequent moisture at the interface will lead to ice forming the bond between protection and substrate.

Ventilation to remove free moisture is also fundamental to all fireproofing application. The use of heat (standard propane is wet heat) removes moisture both from the fire protection and the cement floor. This moisture laden air has to be replaced with warm dry air to eliminate moisture problems. Elevator shafts can provide an effective chimney for air. Where cladding is in place, it may be necessary to remove some windows. Standard hoarding will normally allow sufficient ventilation.

One interesting sideline of the moisture building up at the interface and freezing is the practice of winter insulation of metal buildings from the inside when a sprayed portland cement/mineral wool product is imbedded in an asphaltic based adhesive. Historically, very little problem has resulted from this practice as the moisture at the interface ceases to be a problem, and the open nature of this family of product does not tend to be damaged by ice formation at the insulation/metal wall interface. Some of the older asbestos fire protection products were tested with this type of adhesive, but no testing has been undertaken with today's fiber applications. The nature of gypsum/vermiculite products does not lend itself to this type of adhesive. Gypsum plaster type products must have the substrate above freezing or else the bond will be broken because of ice formation and subsequent melting, or because of ice-lenzing.

A similar substrate vapor problem to the uninsulated metal building can occur in retrofit of roofs when there is only say 12.7 mm (½ in.) of fiberboard as exterior insulation, such that the dew point interfact is not moved away from the substrate. There is not enough thermal insulation outside to prevent water condensation at interior metal surfaces.

Areas of interest to the contractor relative to these problems are further development of temperature gradients using more of the variables such as:

(1) night sky radiative cooling,
(2) phase change after application, and
(3) evaporative cooling effect of sprayed fireproofing.

Also of interest would be ways of fire protecting inadequately insulated roofs and of preventing damage being caused by the dew point occurring at the substrate surface.

Galvanizing

In Canada galvanizing formulations are primarily zinc while in the United States there is also aluminized zinc. Molten aluminum is used in this process; the aluminum oxidizes and weathers very well leading to a component primarily for roof decks not likely to be fire protected.

Zinc galvanizing can be done by electrogalvanizing using electrodes or, what is most commonly used in Canada, hot dip galvanizing [*2*]. Hot dip leads to a thicker coat of zinc than electrogalvanizing so that a wiper is often used to wipe off excess molten zinc.

Wipe coat—7.1 g (¼ oz.) of zinc p.s.f. on both sides.
Hot dip—35.4 g (1 ¼ oz.) of zinc per square foot on both sides.

Because of economics, most steel frame office buildings constructed in Canada use a wipe coat. In use the surface zinc oxidizes and stays whereas unprotected iron will oxidize and fall off. Oxidized zinc forms a good substrate for sprayed fire protecting.

One U. S. deck manufacturer indicated that if they know decking is to be fire protected, they will order steel from the mill that is nonchromated, that is, has no protective finish from the mill over the galvanizing and is either lightly oiled or not oiled at all.

A light oil is then used when roll-forming. Theoretically, this oil vaporizes after three to four weeks and is easily cleaned. Any oil residue should be removed before applying sprayed fire protection!

Adhesion failures to a slick unoxidized galvanized surface are likely to be a function of chromated protection. This protection is applied to the zinc to prevent white rust forming. The white rust is a trade definition for storage stains in the coiled steel from moisture. White rust is more unsightly than troublesome. Chromate can also provide a difficult surface for painting. Chromate is a chemical conversion coating formed by treating the zinc with chromic acid to form zinc chromate. Some paints are compatible with zinc chromate, but, essentially, a paint obtains its bond by etching, and this process can be eliminated by the zinc chromate.

It would appear that the best galvanized surface for sprayed fire protection is one without zinc chromate. However, the amount of chromating is not measured and irregular, and it is the degree of chromating that causes problems.

Where a slick chromated galvanized surface prevents a sound bond with sprayed fire protection, a good procedure is to apply a phosphate type chemical pre-treatment that would etch the surface and lay down a crystal.

On summary, galvanized steel provides an excellent substrate for sprayed fire protection. Questions are raised by oil residue, slick surfaces, and degree of chromating. When in doubt run a bond test in accordance with ASTM Test for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members (E 736–80).

Oily Surfaces

The key factor for a contractor encountering oil surfaces is immediate detection so that corrective measures can be taken.

One of the simplest detection methods is to wipe the surface with a clean white cloth and observe the residue. Oily surfaces can also often be indicated by the bead up of water when sprayed onto the surface. Ultraviolet light makes oil sparkle in a dark area if the oil is paraffin (waxed) base. Falloff or a poor bond strength test based on adhesive failure can also indicate oil residue.

Where there is an oil problem typically it is only one section of the deck. While not always obvious or uniform, suspicions should be raised if there is a splotched appearance. Removal of oil is the responsibility of the deck supplier.

Any oil residue should be removed before applying sprayed fire protection. Water based oil can be removed by hot water or detergent while other types may require a solvent wash. Precaution must be taken when using a detergent wash to ensure that the detergent residue, in turn, is rinsed away. Airless spray cleaning equipment is suitable for this type of cleaning.

Another alternative, which is also suitable for removal of the low-cost silicones, which are replacing oil in some areas, is high pressure steam cleaning with the addition of caustic soda to the water.

Some fire protection manufacturers also suggest use of a water based primer/adhesive over the deck, after cleaning for oil, where suspicions have been raised by the appearance of splotches. It is likely that such treatment performs as much a function of dilutant/cleaner as adhesive.

Painting

Painting of the deck raises more questions in the United States than in Canada where the influence of two major steel companies precludes the sale of black steel. Trade practices have kept down the premium on galvanizing so that it is not worthwhile for deck manufacturers to get into galvanizing and painting whereas in the United States some manufacturers buy black steel and just paint it, which can cause problems. At the time of bidding for the fire protection, the contractor does not know what paint is being used, which can lead to questionable applications.

Under many circumstances, painting can be dispensed with altogether. Research by the Steel Structures Painting Council indicates that rusting of steel only takes place where the relative humidity is above 70% [*3*]. Serious corrosion of steel occurs at normal temperatures only in the presence of both oxygen and water, both of which must be replenished continually in order for corrosion to progress. The thick layer of iron oxides, or mill scale that form on structural steel subsequent to the hot rolling operation provide protection to the steel as long as the scale is intact and adheres directly to the metal. If the mill scale is reasonably intact, it constitutes a good base for painting, and when exposed to mild atmospheres, will give a long and satisfactory paint life. Paint protection in commercial buildings is usually required only while the frame is being constructed. Once the building is enclosed and heated there is normally little chance of any severe corrosion taking place [*4*].

The contractor's position is that paint is not required or necessary under sprayed fire protection, but if present, the painted deck should be tested and listed by Underwriters Laboratories (ULI) or else approved by the sprayed fire protection manufacturer. If not ULI approved, then the manufacturer should indicate whether adhesion is a problem or whether a primer is necessary, and the local authority should approve the assembly for fire resistance.

The contractor's problem is that he does not understand paint chemistry and cannot necessarily rely on the paint specified being used and yet by commencing work, his acceptance of the substrate is assumed.

This problem illustrates the need for performance specifications, but while in Canada the time proven red lead coating is the standard paint finish used on structural steel, the Canadian Institute of Steel Construction/Canadian Paint Manufacturers Association (CISC/CPMA) standard paint specifications limit the performance to "where bonding of concrete to steel is not necessary" as in CISC/CPMA Standard A Quick Drying Primer for Use on Structural Steel (2.75) and CISC/CPMA Standard A Quick Drying One-Coat Paint for Use on Structural Steel (1-73a).

Various epoxy coatings, such as those used in industrial plants, are slick and require the use of a standard manufacturers recommended primer.

Various paint products have unique characteristics. Chlorinated rubber finishes have bood corrosion and bond properties but melt at relatively low temperatures. Inorganic zinc coatings have good corrosion resistance and good heat resistance. Alkyd coatings have good weathering and adhesion properties but can have poor chemical resistance.

Specifically, performance specifications should deal with the compatibility with sprayed fire protection.

Saponification

The increasing demand for industrial exterior fire protection with cement based products having a pH greater than ten lead to the question of chemical reaction with nonalkali-resistant alkyd base paints. The application of cement based fire protection products to structural steel components coated with an alkyd or oil based primer can result in possible bonding failure. This is because of a chemical reaction between the alkaline cement and the acid primer. Chemically the reaction that occurs is described as the, "Alkaline hydrolysis of triacylgcycerous producing glycerol and a mixture of salts and long-chain carboxylic acids."[2] These salts of long-chain carboxylic acids are a crude, slippery soap. The soapy solution forms between the fire protection and the primer reducing the bond between the two components, resulting in possible failure. The term used to describe this process is "saponification."

Some alkyd based paints are resistant to saponification, but unless guaranteed by the manufacturer that a particular alkyd is in fact resistant, extreme caution in proceeding with fire protection is advised. Should any question arise as to the nature of the primer, contact the fabricator of the steel section in question to determine its type.

Upon encountering a suspect alkyd primer, the following are possible alternatives.

1. Complete removal of the alkyd primer from all steel to be fire protected by sand blasting.
2. Covering of the existing alkyd primer with a new primer such as an acrylic, which is chemically unreactive to both the alkyd primer and cementitious fire protection.
3. Running a bond test with a sample area of sprayed fire protection, for this purpose, the sample material can be applied to an overhead section. The material should be kept damp for at least two weeks. Proof of compatability is considered to have been obtained if on removal of material the face of the primed steel shows no sign of saponification.

Rusting

Mill scale is the responsibility of the steel erector/fabricator in the specification, or it is the responsibility of the general contractor to present acceptable steel.

Steel should be cleaned for fire protection by removing all loose rust, loose scale, and dirt.

Illustrations found in the American National Standards Institute (ANSI) Steel Structures Painting Council Surface Preparation Specifications (A#159.1-72) show degrees of both rusting and subsequent cleaning. Lightly rusted steel with no loose mill scale is a good substrate for sprayed fire protection as the mechanical bond reinforces the natural chemical bond.

Hand tool cleaning is normally sufficient to remove loose material and satisfactorily prepares rusted steel for fire protection. The Steel Structures Painting Council have a surface preparation specification that adequately describes different rust conditions and corrective steps.

Some contractors will use a high-pressure air hose (965.27 kPa [140 psi]) to remove loose rust, or else rub the surface with burlap sacking.

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[2] Bond and fire behavior of plaster applied to steel structural sections, steel flooring, and concrete members. Experience gained in tests performed with reference to various corrosion protection and painting agents and to standard specifications and official regulations by Von Dr. Ing. C. Meyer-Ottens and Dr. Ing. Steinert at the University Braunschweig.

Summary

Sprayed fire protection products have problems where the substrate is not kept above freezing. Problems can be predicted by plotting temperature gradients. Some alternatives to avoid problems during severe weather conditions are to:

1. heat and hoard the floor above,
2. use temporary insulation blankets on the floor above,
3. use surface heating lights, and
4. wait for warm weather.

Further research is needed on temperature gradient and phase change.

Galvanized surfaces provide a good substrate for sprayed fire protection where the coating is straight zinc. Problems arise when there is a residue of rolling or protective oil or where there is a further protective coat such as zinc chromate created by the mill. The method for removal of oil residue is a function of the type of oil. A zinc chromate surface may be slick and require etching.

Oily surfaces will lead to a problem with sprayed fire protection, and the deck supplier should be made aware that fire protection is to be applied. Any oil residue should be removed. Most rolling oils should oxidize away within three to four weeks. Various processes from hot water to detergents to solvent wipe are necessary to remove stubborn oil depending on the type. An insurance after cleaning a troublesome oil is to apply primer adhesive.

Painting can cause bond problems unless it is a tried and tested system. Various epoxies are slick and require the use of a primer. Alkyds, unless alkali resistant, can cause saponification with alkali type coatings. Most structural steel in commercial buildings does not require painting for corrosion protection. Performance specifications are necessary for paints that are to receive sprayed fire protection.

Loose scale and rust should be removed before fire protecting. However, light rust provides a good substrate for sprayed fire protection.

The best check on the acceptability of a surface for sprayed fire protection is to apply a sample area and run a bond test when the product is dry.

References

[*1*] Gordan, G. K., "Temperature Gradients," ***Canadian Building Digest No. 36,*** Division of Building Research, National Research Council, Ottawa, Canada, Dec. 1962.

[*2*] Canadian Sheet Steel Building Institute, ***Metric Zinc Coated Sheet Steel for Structural Building Products,*** Technical Bulletin No. 6, Oct. 1979, Toronto, Canada.

[*3*] ***Steel Structures Painting Council Systems and Specifications, Vol. 2,*** Steel Structures Painting Council, Pittsburgh, Pa., 1971.

[*4*] Perchell, J. W. "Economical Coating Protection for Fabricated Steel and Plate," Canadian Structural Engineering Conference, Canadian Institute of Steel Construction, Toronto, Canada, 1978.

Gene Erwin[1]

Inspection Procedure for Field Applied Sprayed Fire Protection Materials: The Need for Standards

REFERENCE: Erwin, G., "**Inspection Procedure for Field Applied Sprayed Fire Protection Materials: The Need for Standards,**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 126–129.

ABSTRACT: This paper deals with the problems and the usefulness of "field inspections" of spray-applied fire resistive materials, which hopefully will develop a useful dialogue leading to the development of an ASTM standard procedure.

To date, neither ASTM Subcommittee E06.21 on Serviceability nor the manufacturers' association has been successful in advancing to an ASTM level, an acceptable procedure. The Association of the Wall and Ceiling Industries-International, working with manufacturers and other interested groups, has developed a procedure that appears to have gained some acceptance and is being used.

This paper will address methods of determining such physical and visual characteristics as substrate condition, thickness, density, bond strength (adhesion and cohesion), finished appearance, and reproducibility of ASTM Fire Tests of Building Construction and Materials (E 119-81) tested assemblies.

It is hoped that this presentation will generate interest in developing an ASTM industry standard procedure readily usable in the "field."

KEY WORDS: fire resistive coatings, fiberous spray applied fire protection, cementitious spray applied fire protection, density measurements, thickness measurements, bond strength determination, field inspection, testing, reporting

If you can visualize a workman,

(1) encumbered by wearing a respirator, goggles, and protective clothing,

(2) holding the nozzle end of a length of hose under pressure,

(3) not necessarily within sight of the worker and machine where the material is being mixed and pumped,

(4) standing on a slippery floor with obstacles and openings, or up on, or out on a slippery scaffold,

(5) in varying lighting or climatic conditions, or both,

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[1] Technical director, Association of Wall and Ceiling Industries-International, Washington, D. C. 20002.

(6) hampered by objects that interfere with the direction of stream or pattern,

(7) with no screeds, grounds, or guides to establish depth,

(8) who may or may not be conscious of the labor and material cost of excessive thickness or inadequate thickness, and

(9) attempting to apply a plastic material at a specified uniform thickness and density to surfaces not uniform in size, shape, direction, or porosity,

you should have no difficulty in grasping the need for standards, both for application and testing.

Fire protection provided by direct spray-applied material is primarily dependent upon the formulation and mixing of the material, the condition of the surface of the substrate and type of substrate, the application procedures, and the severity of the fire exposure versus the resistance rating achieved. There are other factors of course, but the foregoing factors are basic to successful protection.

The formulation of a product is in the hands of its producer and is outside the scope of this paper, except to the extent that the inspection procedure in the field can determine that the label and the contents of the container are identical and that the material was in fact the material used within a test assembly in accordance with ASTM Fire Tests of Building Construction and Materials where its fire resistance properties were determined in accordance with the construction being protected.

For a number of years before 1975, ASTM Subcommittee E06.21 on Serviceability worked actively, as did a manufacturers' association, on developing a standard for laboratory and field inspection of sprayed fire resistive materials, but neither ASTM Subcommittee E06.21 nor the manufacturers' association was able to achieve a consensus standard acceptable to all interested parties.

Technical Subcommittee 4 of the Association of the Wall and Ceiling Industries-International (AWIC), composed of contractors and manufacturing associate members, with assistance from independent testing laboratories, insurance service groups, and interested government agencies received approval of the sixth draft, from the board of directors of AWCI and on 16 April 1975 published the AWCI sponsored "Inspection Procedure for Field Applied Sprayed Fire Protection Materials."

Before its publication, the field testing of in-situ materials was, to say the least, inconsistent, arbitrary, or did not occur at all. The purchaser (owner) could not be certain his structure had the required protection. Occasionally the contractor would apply more than the specified thickness to be sure he had met the contract requirements. There was very little consistency in the industry and a great deal of competition.

It is necessary to recognize that an inspection procedure is not intended, nor can it be used as a basis to determine the suitability of any particular material or brand for a specific assembly or specific usage.

The primary objective of an inspection standard, as with all such procedures, is to offer the purchaser of spray-applied fire protection a method of reasonably assuring himself that he has received what he paid for and at the same time offer the seller a method of reasonably assuring himself that he has complied with the requirements of the contract in a consistent manner.

As with any test or inspection standard, repeatability or consistency is of key importance. Consistency of procedure in measuring physical characteristics and consistency in interpretation of the measured results are vital in determining that an application is as close to being identical to the test assembly as is possible and therefore should perform similarly to the test.

The following are requirements for a testing standard.

1. A testing standard should provide guidance for testing material applied to various types of structural members such as beams, columns, floor systems, and related components. Some of these terms require thoughtful definitions to avoid confusion or disagreement about the number and type of measurements to be made.
2. A testing standard should be capable of being incorporated by reference or directly into a contract or specific document to provide a basis for establishing field test procedural requirements.
3. A testing standard should establish the qualifications for testing authority personnel to enter the premises, to review the records of the owners' representatives, and to perform their designated functions. It could include observation of the application in progress.
4. A testing standard should provide, in jurisdictions where building authorities are responsible for thickness inspection, or other measurement determination, that the remaining testing requirement procedures deemed necessary be carried out by an independent testing authority.
5. A testing standard should require an independent laboratory to perform the specific tests. A testing standard should require that the test findings will be reported simultaneously to the owner or his representative, the general contractor, and the fire protection contractor.
6. A testing standard should specify the amount of time permitted for reporting the findings to enable the applicator to perform any necessary corrective work while the tested area is still available for ready correction of cited deficiencies.
7. A testing standard should require that the owner or his representative make available to the inspecting agency, the accepted description of the ASTM E 119-81 tested design including sufficient details for the purpose of inspection.
8. A testing standard should require that the testing/inspection agency determine that the fire protection material has been correctly identified and labeled by an accredited agency providing inspection and labeling services, as being the material used in the selected design.

9. A testing standard should clearly describe all of the tools, materials, and equipment required to successfully complete the prescribed tests in addition to clearly describing the step by step procedures necessary for accuracy.

The AWCI publication, "Inspection Procedure for Field Applied Sprayed Fire Protection Materials," while certainly not perfect, does, in our opinion, provide the needed field test procedures.

There are certain statements in this document that are subject to interpretation for lack of more specific definitions or descriptions. Two examples are:

1. Substrate should be free of dirt, oil, grease, release agents, loose scale, loose paint, and any extraneous materials. Areas not in compliance with the material manufacturers' specifications shall be reported to the general contractor or owner, or his representative, or both for correction. Some concrete form release compounds are clear and practically invisible. Some structural steel is left exposed for lengthy periods. Some aluminum surfaces are silicon coated. A more precise and graphic gage is needed upon which to base the decision that the substrate is suitable to receive the fire protection material.
2. One out of every four bays or similar units shall be inspected, but in no case shall a bay or unit exceed 232 m^2 (2500 ft^2). Is this definition of a bay sufficiently clear to avoid misinterpretation about how many measurements are to be required?

There may be other statements or procedures that can be improved, however, such improvements must come from a larger body of interested persons.

It is my intention to submit this AWCI document to the appropriate subcommittee of ASTM E06 as a first draft document for an ASTM standard inspection procedure.

Gregory T. Anderson[1]

Automatic Sprinklers Versus Direct Applied Fire Protection: Can There Be Trade-offs?

REFERENCE: Anderson, G. T., "**Automatic Sprinklers Versus Direct Applied Fire Protection: Can There Be Trade-offs?**" *Fire Resistive Coatings: The Need for Standards, ASTM STP 826,* Morris Lieff and F. M. Stumpf, Eds., American Society for Testing and Materials, 1983, pp. 130–139.

ABSTRACT: Trading off one form of fire protection for another is becoming a common place occurrence in construction today. On both a national and local level, building codes are allowing direct substitution of one form of fire protection for another. The objective of this paper is to question the justification of this concept as it applies to automatic sprinklers versus direct applied structural steel fire protection. It is important to keep in mind that structural steel fire protection is intended to maintain structural integrity in a fire while automatic sprinklers are a mechanical extinguishing system. The end result is that both systems complement each other and were never intended to replace one another.

KEY WORDS: fire protection, fire resistant materials, steel construction, sprinkler, building codes, fire safety, fire resistive coatings

The following are some of the questions being asked by designers and building code officials as owners, manufacturers, and insurance companies take positions for and against the use of automatic sprinklers.

1. What is meant by fire protection trade-offs?
2. What are we trading off?
3. Are trade-offs of structural fire protection for mechanical extinguishment justified?
4. What issues need to be addressed in standards to improve building performance and guarantee life safety in building fires?

Addressing those questions while defining the roles that automatic sprinklers and direct applied fireproofing play in the fire and life safety performance of today's structures raises the issue of whether there can be trade-

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offs of one form of fire protection for another without sacrificing structural or life safety or both.

The term "trade-off" can be interpreted to mean the giving up on one type of fire protection for another while offering an equivalent level of fire safety. Justification of the definition must be based on a complete evaluation of historical performance in actual fire situations and not selective numerical interpretation of fire statistics, for example, misleading references to reports, such as "Automatic Sprinkler Performance in Australia and New Zealand, 1886–1968," which stated 99.76% satisfactory performance of automatic sprinkler systems [*1*]. Typically the presenter fails to mention that buildings equipped with automatic sprinkler systems that were not in commission at the time of the fire were omitted from the analysis. Or, that structural integrity in Australia is achieved through fire resistive construction. Fire resistance is not traded off when automatic sprinklers are added.

When numerical interpretation, such as this occurs, the word "trade-off" can take on a different definition. It may now actually imply the giving up of some protection. The facts are according to the New South Wales Government [*2*] that "In Australia, a sprinkler system is used as an adjunct to the fire resistive and compartmentation integrity of the building to produce a total system of fire safety." Each method of fire protection is evaluated on its own merit and contribution to attaining the goal of a complete fire and life protection system.

At the turn of the century, major financial losses were usually associated with massive structural failures. The structural performance of building elements in fires became the center of interest and lead to the development of the standard fire test and methods of maintaining structural integrity. Two assumptions were made:

1. That fire spread by destruction of, or thermal conduction through, compartments and compartment boundaries.
2. The severity of a fire increases roughly in proportion to the specific fire load. As the fire load increases the ability of the structure to withstand structural and thermal failure must increase.

This concept lead to development of methods for maintaining structural integrity as they related to steel frame construction. It started with concrete encasement, evolved to lath and plaster, and beginning in the late 1940s shifted to direct spray-applied fireproofing.

Spray-applied fire protection isolates the structural member from the fire by forming a barrier that retards the transfer of heat from the fire to the steel. Hence, the potential for progressive collapse of the building is reduced.

Harmathy [*3*] has stated the success of this approach to fire protection can be substantiated by the fact that "the spread of fire in structures today is rarely caused by structural failure."

As the industrial sector of our economy developed, the value of contents and operations increased. Automatic sprinklers became a practical mechanical method of reducing financial losses by aiding in the extinguishment of the fire. As Averill [4] has stated, "From the beginning, the justification for installing sprinklers was to protect property." I must mention that in order to perform this task, structural stability had to be maintained. Early on, the fire protective function performed by both spray applied fireproofing and automatic sprinklers was defined.

It becomes obvious that the motivation behind the development of most fire protection systems has been and remains financial. In order to justify this statement we have to define the difference between fire protection and life safety protection.

Fire protection generally refers to the protection of the building and its contents as deemed necessary by the owner or building code. It may include structural fireproofing, compartmentation, smoke control systems, standpipes, automatic sprinklers, or all of these.

You will typically find exit travel distance, fuel contribution, flame spread and smoke development characteristics of interior finishes, means of egress, emergency lighting, and alarms as typical life safety protection systems. All these are usually mandated by regulatory building codes to ensure safe occupant egress from the building.

The success or failure of any or all of these systems in providing life safety in the event of a fire can be only based on actual fire performance.

Accurate fire death statistics, such as those found in Ref *5*, have only recently become available. From 1977 through 1981 an average of 6050 civilians died annually in structure fires across the United States with 96.1% (5814) of the deaths occurring in residential structures [*5*]. In other words, an average of 236 people per year have died in U.S. structure fires excluding residential out of a total population exceeding 200 million people.

Since a small percentage of general structures have sprinklers today, it is logical to conclude that fire resistive construction consisting of noncombustible, limited combustible, and combustible classifications depending on occupancy offer excellent life safety protection. Therefore, what we have to ask ourselves is: How large of a financial burden can I afford for fire protection of my building and contents? As in Ref *6*, "Estimates of the number of structure fires indicate little change from year to year, and show that on the average 1 057 800 structure fires occurred annually, accounting for 36% of all fires." These fires represented an estimated property damage of $4 125 000 000 in 1977 compared to $5 976 000 000 in 1981. This converts to an average loss per structure fire in 1981 of $5650.

Although on an individual basis you can see that the burden is relatively small, the accumulative total is quite costly. That total figure is the predominate reason why insurance companies are a domininant force in the National

Fire Protection Association (NFPA) and actively support automatic sprinkler research efforts at Factory Mutual (FM) and the National Bureau of Standards (NBS) Center for Fire Research.

Their support and participation in all of these organizations is directed at reducing the potential for and impact of large loss fires (direct fire damage of $1 million or more). As in Ref *6*, "The large-loss fires reported in 1981 accounted for only .01 percent of the total fires, but the direct dollar loss attributed to these fires accounted for 12.3 percent of the overall property loss." This information forms the basis for the insurance companies support of the automatic sprinklers industry.

But at what cost, and at whose expense are sprinklers being encouraged? Recent estimates for installation of automatic sprinklers range from $9.30 to $14.00/m^2 ($1.00 to $1.30/ft^2) [*1*] of building area in new construction and can be more than twice that when retrofit. The problem arises when trade-offs in various building types, such as those listed below, form the economic basis for justification of sprinkler protection [*8*].

1. Reduced fire resistive ratings of structures and components.
2. Elimination of physical barriers that confine the fire.
3. Substantial increases in allowable floor areas.
4. Increases in the number of building stories without a change in building classification.
5. Increased flame spread and smoke development ratings of interior finishes.
6. Increases in exit travel distances.

Consider this question. Is the 13.9% failure (one in seven) reported by Factory Mutual [*9*] in sprinklered buildings any more acceptable than a 10.1% unemployment rate?

At the expense of other proven fire and life safety systems, I say, "no!" Automatic sprinklers are a mechanical extinguishing system designed to reduce the spread of a serious fire hazard by controlling fire growth. To this end, their performance is well documented.

Trade-offs of fire and life safety features when automatic sprinklers are added should not be considered until near perfect performance in providing all of the essential life safety protection in a building can be achieved.

In order to improve building performance and guarantee life safety in today's structures, the fire protection industry must continue to take a critical look at the environment in which these systems are required to perform. Realistic performance standards must be then established based on that environment. Specific product or system performance levels when tested according to standard test methods should not alter the necessary industry levels of performance required for fire and life safety.

In the case of sprayed fireproofing products:

1. They must be applied at proper thicknesses and density. Thickness checks and density specimens of the fireproofing product should be taken on each floor of the project, at randomly selected locations from beams, columns, and floor or roof assemblies. Typically one test for each 929 m^2 (10 000 ft^2) of floor area is recommended. Particular attention should be given to flange thickness and density of material in areas generally not accessible from the floor.
2. Minimum levels of physical performance need to be determined. Neither Underwriters Laboratories Inc. fire resistance tests nor a product's inherent physical performance results in standard test procedures, such as ASTM Test for Cohesion/Adhesion of Sprayed Fire Resistive Materials Applied to Structural Members (E 736-80), should be used to establish minimum or maximum acceptable levels. The minimum or maximum level of performance necessary to resist accidental damage and physical abuse during construction and for the life of the building are what is required. Again, these performance levels should be based on the building type and environment, not product characteristics.
3. Final inspection is vital to long-term performance. Areas where the fireproofing has been damaged or removed must be restored to ensure structural integrity in a building fire.

New standards for automatic sprinklers are not an issue. A review of the reams of information on sprinkler performance quickly indicates that broad interpretation of this data has taken place.

One possible way of filtering through fire damage reports to determine sprinkler effectiveness ratings would be development of a standard approach for fire investigation.

Regardless of the satisfactory performance level claimed for automatic sprinklers, their effectiveness could be significantly improved by implementing a mandatory testing and inspection program.

This should be done a minimum of once per year. This position could be defended on the basis that sprinklers are a mechanical extinguishing system subject to the same breakdowns, repairs, and maintenance of all mechanical hardware.

The fire protection function performed by both automatic sprinklers and spray applied fireproofing is vital to life and financial protection in today's structures. Both systems perform different but have very critical roles. Tradeoffs can only reduce their effectiveness in performing the function they are designed to perform. The importance of their fire protection role in future construction can only be based on past and present performance. To this end, we must continue to improve performance and effectiveness of all fire and life safety systems.

References

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[*5*] "U.S. Fire Experience Highlights, 1977-1981," *Fire Journal*, Sept. 1982, p. 70.

[*6*] "1981 Large-Loss Fires in the United States," *Fire Journal*, Sept. 1982, p. 32.

[*7*] Fleming, R. P., *Buildings*, May 1982, pp. 51-55.

[*8*] Barris, J. P. and Conte, D. L., *Sprinkler Trade-Offs: Are They Justified, Fire Journal*, May 1980.

[*9*] Miller, M. J., *Risk Management and Reliability*, Systems Safety Society, Washington, D. C., 1977.

DISCUSSION

Recorded Discussion

Charles Almand[1]—Where did the 3.9% failure rate for automatic sprinklers come from?

G. T. Anderson—Factory Mutual report "Risk, Management and Reliability Systems and Safety Society" presented by Mr. M. G. Miller in Washington, DC, 1977.

David Moore[2]—I have a few statements! The large loss fire data base that you are referring to is obviously not the sole basis for insurance support. I think instead it is the other fires involving failures. If you look at those large loss fires, the majority had no sprinkler systems and most likely that is the reason they spread to the extent they did.

G. T. Anderson—That is an erroneous assumption since the information does not define whether the structure was sprinklered or unsprinklered.

David Moore—But references you made were not solely fires where sprinkler systems failed.

G. T. Anderson—That is correct, but they are large loss fires.

David Moore—What I am saying is that of the large loss fires that occurred over the years that have been documented, the majority of those have been unsprinklered buildings.

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[1] U. S. Gypsum Co., 1050 17th St., NW, Suite 1150, Washington, DC 20036.

[2] Mobil Research and Development Corp., Princeton, NJ 08540.

G. T. Anderson—That is a true statement. What you have to remember is that only a small percentage of all structures today are sprinklered.

David Moore—You have to look at the performance record of sprinkler systems. Fire protection engineers have considerable amounts of data on successful performance as well as unsuccessful performance. We do not have a considerable amount of well documented data on fire performance of any other building materials. I think this is where trade-offs come to light in the first place. There's nothing to support that trade-offs are not a viable alternative. In fact, there is plenty to support that they are.

G. T. Anderson—I don't disagree with you, and, in fact, I am not against the use of sprinklers in buildings. In fact, I encourage their use. My point is that they are not an end all, and they are being promoted as such in many of the code changes suggested today.

David Moore—I think that there are some extremists. There has to be a proper blend, but we can't say that sprinklers have not been useful and that there is no trade-off possible.

G. T. Anderson—We are not in disagreement. Do you have any statistics on failure rate with spray applied fireproofing that was poorly installed in a building? We need to know what kind of failure rate we have in our industry. There are a lot of failures out there, and there are companies who misrepresent themselves as quality fireproofing products.

Other manufacturers have made the statement that they have never had a spray applied fire protection product fail when correctly applied. The question therefore becomes, when it has failed, was it correctly applied? For this reason, W. R. Grace and Company has taken a strong stance in support of job-site inspection procedures by independent testing laboratories. We encourage them on every job, and, in fact, we recommend to the general contractors that it be done. It is a concern, a very viable one.

Question—Factory Mutual reports are based on failures of fireproofing systems for one reason or another. It would be helpful to keep records of correctly installed fireproofing systems as well as incorrectly installed fireproofing systems, and then compare failure rate.

G. T. Anderson—Though that would be helpful, the best approach would be to ensure that all fire protection systems are installed correctly. ASTM has developed field thickness and density test methods for spray applied materials. These test methods have been adopted by AWCI, the people who apply the products as well as the manufacturers of the fire protection materials.

Written Discussion

R. G. Gewain[3]—The author has asked excellent questions at the beginning of his paper but then does not follow through with his presentation on each item. The paper does not contain sufficient information to support the author's position on trade-offs in structural fire protection when an automatic sprinkler system is provided.

For example, on p. 131, the two primary reasons given for the excellent record of performance for automatic sprinklers in Australia are that (1) maintenance contracts are insisted upon by insurers and (2) all water flow valves are monitored by land lines connected to the nearest fire station. Also it is important that the author point out that Mr. Marryat, author of the book *Automatic Sprinkler Performance in Australia and New Zealand,* defines "acceptable level of loss" as a percentage of the total value of the risk. Those who disagree with this definition believe it should be based on a fixed area of damage irrespective of the total size or value of the risk or else on the number of sprinkler heads caused to operate.

The author correctly raises the question of structural integrity but does not discuss reliability of sprinklers or the reliability of structural fire protection as it impacts on structural fire damage in real fires. Anderson compares the performance of fire protection in laboratory fire tests to sprinkler performance in real fires. The two fire exposure conditions, unless further modified and explained, do not make for a reliable comparison.

For example, review any of the major fire losses discussed in the *NFPA Fire Journal* involving unsprinklered buildings that have a 2- or 3-h fire resistance requirement for the building construction; the resulting fire damage includes the replacement of the structural elements even though the construction performed as designed in the standard fire test. On the other hand, in buildings with automatic sprinkler fire protection, less damage is usually observed for the structural building elements because the sprinklers control the fire exposure, thereby reducing fire temperatures below critical temperatures causing damage to the steel. The ASTM E 119 fire represents an uncontrolled fire. However, if the fire never reaches the intensity specified by the ASTM E 119 test, is this not a measure of the satisfactory sprinkler protection of the structural elements? And on what basis are the code specified ratings determined? Experience and research indicate the premise that fire load equals fire resistance duration is not valid.

Attached is a discussion on the reliability and comparison of active and passive fire protection. It would have been helpful if the author had presented some basis for improving the reliability of automatic sprinkler systems

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[3] American Iron and Steel Institute, 1000 16th St., NW, Washington, DC 20036.

rather than dismissing the subject by indicating this is not possible but giving no substantiation for this position. There is an excellent study published in England, which studied 10 759 fires in sprinklered buildings during 1974 through 1979. The conclusions of that report are quite different from the author's.

It would have been most helpful in considering the pros and cons of this argument if the author had included some record of building fires where there existed properly designed automatic sprinkler system. Then a useful comparison could have been made with fires involving unsprinklered buildings with fire protected structural elements as well as compartmentation.

On p. 133, it would have been helpful if the author had more specific information on the loss statistics related to structural damage. It is my understanding that loss statistics show less damage to the structural elements, fire protection, and building service equipment, such as air conditioning, and so forth, where the building is properly sprinklered. If I am not mistaken, Mr. W. Robert Powers of the New York Board of Fire Underwriters published a paper several years ago specifically discussing this subject as it relates to high-rise office and residential occupancies in New York city.

In the percent failure reported by Factory Mutual as discussed on p. 133, it should be made clear that the bulk of the Factory Mutual coverage is for should be made clear that the bulk of the Factory Mutual coverage is for low-rise industrial and mercantile buildings, not high-rise buildings for business or residential use. However, if the author is relating the failure of sprinklers as reported by Factory Mutual to high-rise buildings for offices, hotels, schools, and so forth, those occupancies ought to be specifically identified. This is a very unclear discussion if the author is dealing with Building Code Trade-Offs for high-rise buildings only. In a paper such as this, I believe the author should use the basic Factory Mutual data or additional supporting evidence rather than Factory Mutual's conclusions.

On p. 6, Item 2, what is the record of performance either in standard fire tests or in actual building fires when the application of the fire protection material correctly follows the manufacturers[1] instructions? There are not too many perfect jobs, but code requirements for fire resistance are based on laboratory tests in which the specimens are constructed with "white gloves." What percentage of fire protection material removal can be tolerated before significantly affecting the performance of a construction in either "real world" fires or laboratory fire tests? As you know there are many instances where spray-applied fireproofing is removed to permit the installation of ductwork, hangers for building service equipment, sprinkler piping, or suspended ceiling systems. This question is extremely important in that the author's whole premise for comparing sprinklers and structural fire protection material is based on laboratory fire tests of fire protection material used to establish fire resistance ratings in building codes while the discussion of sprinkler performance is based on the field experience of automatic sprinkler protection. The author has not established the validity for a comparison on such widely different approaches.

G. T. Anderson—no response.

GENERAL DISCUSSION

Morris Lieff (symposium chairman)—I just want to thank you all for being here. We are delighted with the attendance and participation, and, frankly, I feel pretty good about the symposium. It turned out better than I hoped it would. I do want to repeat that ASTM E6.21 on Serviceablity is a subcommittee that is working in the area of fire resistive coatings, and we would welcome cooperation from many of you here who are not members. We would particularly invite the people of the intumescent and the magnesium oxychloride group to join in our work. We have been trying to write a specification for sprayed materials but can't do it without your help, and we would really welcome participation of people from your companies to join our work, so that our working group is a complete spectrum of the field.

Robert Levine[1]—I would like to ask the group a question. Bob White's paper was on use of coatings on wooden structures. Almost everything else has been on new construction and use of coatings on steel. I've had several conversations with people on the subject of retrofit, I was wondering whether anyone here would make some comments on retrofitting?

Morris Lieff—Have you all heard what Dr. Levine was saying? He would like some comments on the retrofitting of wooden structures with coating.

Frank Stumpf[2]—I have a comment. In the case of sprayed fibers, there's been some retrofitting on wood. In the case of wood because wood does wet, on wetting does tend to warp, it's necessary that the wood be secured by some sort of metal lath or chicken wire to receive the sprayed fire resistive materials, and this has been done in many cases in several old cathedrals. They have extensively sprayed them to protect the wood joists and wood frames.

Questioner—The insulation people have statistics that show only 1% of construction is new construction and 99% for all existing buildings; so our replacement rate is 1%, approximately both residential and commercial building.

Frank Stumpf—Good point.

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[1] Fire Research Resources Division, Center for Fire Research, U. S. Department of Commerce National Bureau of Standards, Washington, D. C. 20234.

[2] U. S. Mineral Products Company, Stanhope, N. J. 07874.

Morris Lieff—So there's a big area for retrofit. I know that in some areas some municipalities have shown interest in upgrading the fire resistive qualities of wooden residential by retrofitting with sprayed fire protection materials.

Summary

The symposium is introduced by Lieff's paper on "Fire Resistant Coverings," which provides a general description of American fire protection coatings. The materials are divided into two broad categories based primarily on thickness: one group consisting of thin paint-like coatings that are fire retardant and the other consisting of thick coatings that are used to provide fire resistive protection of steel. The characteristics and composition of intumescent, nonintumescent, thick insulative, and ablative materials are discussed. Standard methods for evaluating the fire retardant and fire resistive properties of the coatings are described.

Stumpf outlines mineral-fiber compositions for spray-applied fire resistive coatings. They are factory mixed products consisting of manufactured inorganic fibers and proprietary binders. Air setting, hydraulic setting, and ceramic binders are used singly or in varying combinations and quantities depending on the use for which the product is designated. The fibrous materials most commonly used for fireproofing generally range in applied density from 0.2 to 0.6 g/cm^3 and range in applied thicknesses from 1.0 to 6.0 cm on decks and up to 8.0 cm on beams and columns. The spraying process is generally performed with a specially designed machine that feeds the dry mineral fiber composition to a spraying nozzle where the fiber mixture is enveloped with water as it is sprayed onto the surface to be protected. Fire resistant characteristics and other important properties, such as insulation and acoustics, resistance to air erosion and corrosion, are discussed.

White describes the results of small-scale fire resistance tests on plywood panels protected with eight commercially available fire retardant and fire resistive coatings. Fire retardant coatings consisting of latex emulsion, two-component epoxy intumescent, polyurethane intumescent varnish, alkyd intumescent varnish, and alkyd intumescent coating improved the fire resistance of 16-mm (⅝-in.) plywood specimens by up to 15 min. While a single coat produced only a gain of 2 min, multiple coats or 0.5 mm (0.02 in.) total thickness show a gain of 15 min above uncoated plywood that had an endurance time of 11 min, thus providing a thermal barrier of 26 min. Fire resistive coatings consisting of trowel-applied water-based single component flexible mastic coating, sprayable ablative coating using polymer binder, and sprayed mineral-fiber and spray-applied ablative epoxy two-component intumescent mastic coating provided more protection than fire-retardant coatings as expected. A 6.4-mm (0.25-in.) thick mastic coating provided up to a 40-min endurance period, and using a 35-mm (1.4-in.) thick mineral-fiber coating a 55-min thermal barrier was achieved. White concludes that fire resistive coatings can significantly improve the fire resistance of wood constructions.

Bardell presents a two-dimensional heat-flow analysis designed for prediction of the fire resistance of hollow steel columns. She describes the insulative value of spray-applied mineral-fiber and cementitious fire resistive coatings for steel building columns. Thermal conductivity and volumetric specific heat were determined, and the results of these high temperature property tests were used as input for the heat flow analysis. The predictions of fire resistance were verified by full-scale fire tests on unloaded hollow (round and square) steel columns, protected with the sprayed mineral fiber and cementitious coatings. Test steel temperatures were found to be substantially higher than those predicted by analysis based on thermal conductivity and specific heat values obtained in the thermal property tests. Two reasons are presented for this discrepancy. First, the columns, particularly the 60-mm (2.4-in.) cementitious column contained free water resulting from an insufficient conditioning period to allow adequate drying of the material. Second, thermal conductivity measurement can only be made up to 600°C (1100°F). However, most of the protection material was at or above this value for a greater part of the fire resistance period. Bardell concludes that thermal properties of spray-applied fire protection materials are essential pieces of information in predicting fire performance of steel columns and that fire resistance is very sensitive to the thermal conductivity of the coating materials.

Schultz outlines the use of small-scale fire tests of columns in evaluating fire resistive coatings. A small furnace is defined as one that can perform in accordance with ASTM Fire Tests of Building Construction and Materials (E 119-82) on columns with a minimum height of 0.9 m (3 ft). He describes the characteristics of various American and Canadian furnaces used both for large- and small-scale tests. The project sponsored by the American Iron and Steel Institute (AISI), to determine the feasibility of using a combination of full-scale and small-scale ASTM E 119 testing and calculations to provide a data base for determination of fire ratings of interested column size, is reviewed. The small furnace was also used to test columns protected with fire resistive coatings using high-intensity fire conditions, that is, a time–temperature curve that reaches 1093°C (2000°F) within 5 min and maintains that temperature for the duration of the test. Schultz concludes that the use of a small-scale ASTM E 119 test of 0.9-m (3-ft) columns is feasible and valid, and correlates well with equivalent full-scale tests.

Gratzol et al reports fire tests on two sets of W10X49 steel columns, 1.5-m (5-ft) high protected with five different fire resistive materials. One set was tested in accordance with ASTM E 119, and the second set was tested using the hydrocarbon time/temperature curve (also called high-intensity fire). The five protective materials were (1) portland cement with exfoliated vermiculite without fiberglass reinforcing, (2) portland cement with proprietary fillers including fiberglass reinforcement, (3) magnesium oxychloride based proprietary cement, (4) intumescent epoxy, and (5) dense concrete. In the high-intensity test the furnace reaches the desired 1093°C (2000°F) temperature in 6 min with a protected specimen. The authors found that the fire endurance is reduced in the hydrocarbon pool fire environment. However, the exposure of the protective materials to the proposed ASTM E 5 pool fire does not exhibit any significant difference for thermal shock from the ASTM E 119 test. They conclude that there is a measurable relationship between the two test methods that provide data to forecast the result of one to another for a given furnace and set of circumstances.

Belason, a symposium attendee, has submitted a critique of Gratzol's controversial paper, which is included in this book because of its comprehensive treatment. Belason questions the fabrication of the test specimens, inadequate heat flux measurements on the high-intensity fire, and the authors' data analysis and conclusions. Belason also questions the propriety of using the hose stream on a column since ASTM E 119 has never required hose stream testing on individual members, and finally critically reviews the authors' performance comparisons among generic coatings.

Herrera compares magnesium oxysulfate and magnesium oxychloride cements for fire resistive uses. Magnesium oxysulfate cements begin to decompose at temperature of 900 to 1100°C (1650 to 2000°F), much higher than the 370 to 530°C (700 to 1000°F) temperatures at which magnesium oxychlorides break down, thus providing longer fire protection. At elevated temperatures oxysulfates yield sulfur dioxide whereas oxychlorides give off hydrochloric acid; the latter being much more corrosive. The oxychloride cements are more susceptible to weather conditions and may partially form unstable magnesium hydroxide instead of magnesium oxychloride resulting in "dry set" with resultant loss in bond and volumetric stability as well increased corrosion and cracking. The magnesium oxychloride cements have the advantage of being harder with twice the abrasion resistance than corresponding oxysulfate mortars. Both have excellent bonding properties. The author concludes that both oxysulfate and oxychloride cements provide excellent fire resistive coatings, but the oxysulfate cements are best suited for spray-applied fire resistive coatings.

Lieff reviews the use of fire resistive coatings in wood and steel construction in the U.S.S.R. The process of development of Soviet standards and norms are described. In particular, phosphate-type coatings both intumescent and nonintumescent are discussed. English translations of two Soviet (GOST) standards for Fire Protective Phosphate Coatings for Wood and for Steel are included in accordance with ASTM style.

Berry discusses the problem of the preparation and acceptance of steel surfaces to receive sprayed mineral fiber and cementitious fire resistive coatings. Conditions that may create problems in the application of the fire resistive coatings are outlined. If the substrate is not kept above freezing, problems occur, such as subsequent drop-off, when the substrate warms. Temperature gradients are provided for roof and floor sections, which permit prediction of problems during subfreezing conditions. Recommendations are given for avoidance of such problems by heating or use of temporary insulation blankets on the floor above or waiting for warm weather. Galvanized surfaces provide a good substrate for sprayed fire resistive coatings where the surface is straight zinc. Problems arise when there is a residue of oil or the zinc has been modified to zinc chromate, which create a slick surface. Since oily surfaces may result in bond failure, detection of oil on the substrate surface and its removal are necessary. Techniques for oil removal are described. Painting may cause bonding problems. Epoxy paints are slick and require use of a primer. Alkyds, unless alkali resistant, may saponify with alkaline fire resistive coatings. Most structural steel in commercial buildings does not require painting for protection from corrosion. Loose mill scale and rust should be removed, but light rust provides a good substrate for sprayed fire resistive materials.

Erwin discusses the needs for standards for both application and testing of fire resistive coatings. The primary objective of an inspection standard is to offer the purchaser of the spray-applied fire protection means for assuring that he received what he paid for as well as offering the seller a method of reasonably assuring himself that the requirements of the contract have been complied with in a consistent manner. The requirements for field inspection of fire resistive materials are outlined as follows:

(1) identification of product by label as being material used in ASTM E 119 test assembly upon which the fire retardant rating is based,

(2) guidance for the testing of material applied to various structural elements, such as beams, columns, floors, and roof systems,

(3) reference documents to provide a basis for establishing field test requirements,

(4) provision of qualifications for testing authority personnel to enter premises to observe and evaluate application as it progresses, specified tests to be made by an independent laboratory and reported to the owner, general contractor, and fire protection contractor.

Timely reporting should be made to enable the contractor to perform any necessary correction of cited deficiencies while the tested area is still available for ready corrections, including criteria for providing data to be used in making a determination that the selected material and its installation have met requirements of the specification with respect to substrate, thickness, density, bond strength, finished condition, repair, and patching.

Anderson discusses automatic sprinklers versus direct-applied fire protection. He points out that trading off one form of fire protection for another is becoming common place in construction. He raises five questions: What is meant by fire-protection trade-offs? What is being traded off? Are trade-offs of structural fire protection for mechanical extinguishment justified? If so, how? What issues need to be addressed in standards to improve building performance and guarantee life safety in buildings? Anderson points out that structural steel fire protection is intended to maintain structural integrity in a fire while automatic sprinklers are a mechanical extinguishing system. He concludes that both systems complement each other and were never intended to replace one another.

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