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Industrial Fireproofing—Setting the Story Straight

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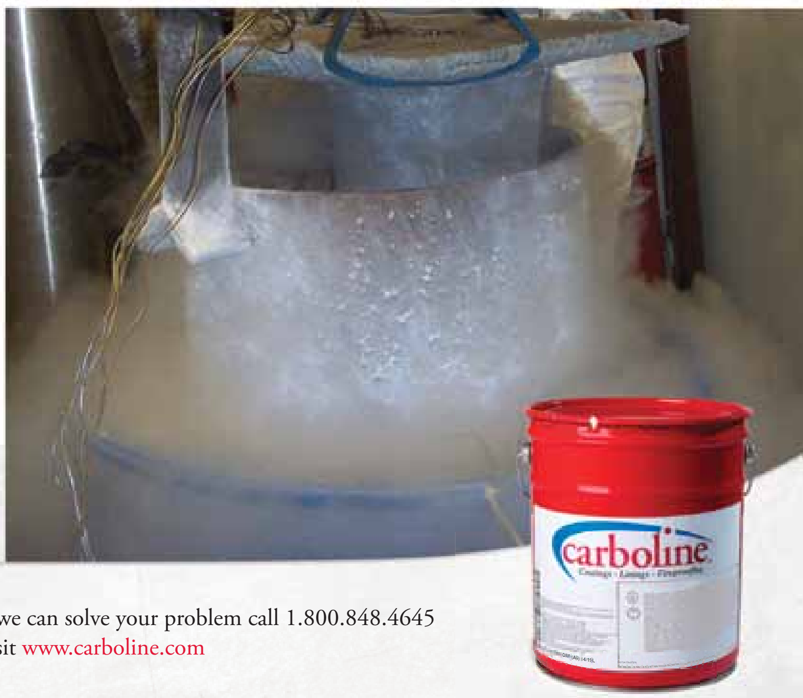

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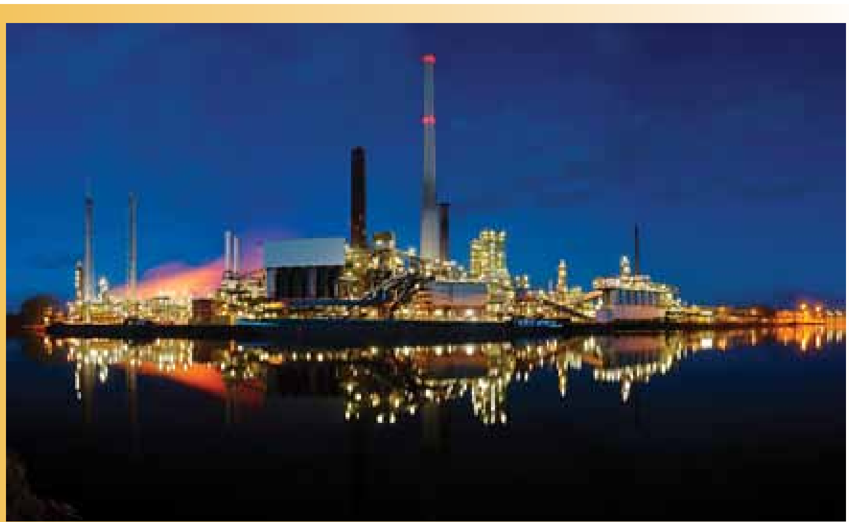

Saving Lives and Assets with Industrial Fireproofing

Fireproofing plays a critical role in protecting personnel, equipment, and infrastructure from collapse and failure in both the public and private sectors. These materials are used to maintain the integrity of structural elements, protecting them from collapse for a given amount of time when exposed to fire.

Fireproofing system selection is similar to materials selection in that many factors need to be considered, including types of exposure, operating conditions, substrate, application conditions, environmental regulations, cost, time constraints, and design/fabrication considerations.

When an environment is at substantial risk for fire—such as in petrochemical plants, refineries, or offshore oil and gas platforms—the incorporation of a passive fireproofing coating must be considered and implemented. These fireproofing systems are commonly used along with an appropriate corrosion-resistant primer to provide fire protection as well as corrosion resistance.

This special supplement to *Materials Performance* covers the types of passive fire protection (PFP) coatings available, pertinent regulation and testing requirements, their properties, how and where they are used, and how to implement them successfully. It also dispels several myths about such issues as their long-term durability, moisture adsorption, role in corrosion protection, and variable spray-applied density.

In use for more than four decades, PFP coatings are a vital and integral part of protecting people, assets, and the environment in the potentially hazardous conditions experienced in many industrial environments today.

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Industrial Fireproofing: Setting the Story Straight

Designed for use on structural steel in refineries, petrochemical plants, liquid natural gas facilities, and industrial manufacturing environments, passive fire protection materials have a long track record of proven performance.

Introduction

In petrochemical and industrial environments, the threat of fire is constant. Planning to provide fire protection to personnel and equipment is a necessity. During a typical hydrocarbon fire, structural steel is exposed to temperatures reaching 2,000 °F (1,093 °C) within minutes. At 1,100 °F (593 °C) steel retains only 50% of its original strength and load-bearing capacity. For this reason, passive fire protection (PFP) materials are used to extend the structural life of steel during a fire event. This allows time for personnel to escape safely and more time for firefighters to respond, saving lives and assets (Figure 1).

Industrial PFP must go through a litany of stringent testing to be certified for use. Standard test methods have been vetted over the last 40 years to accurately predict performance of fireproofing products. Standard bodies such as Underwriter's Laboratories (UL), British Standards Institute (BSI), International Standards Organization (ISO), and NORSOK [1] include testing standards for industrial fireproofing materials. Products must be tested by certified laboratories to evaluate fire endurance, physical performance, and weathering resistance while in service. For industrial fireproofing, fire testing is modeled directly after the rapid rise in temperature that occurs in a hydrocarbon fire and/or jet fire exposure. Testing that simulates an explosion, cryogenic spill, or firefighting measures such as hose stream endurance may also be included depending on the facility and certification that is sought. Exact parameters of the testing programs vary depending on the intended service.[2]

All test data are reviewed by certifying bodies such as UL, Det Norske Veritas (DNV), Lloyd's Registry of Shipping (LRS), and the American Bureau of Shipping (ABS) to confirm the validity of the data and determine the thickness requirements for the individual fireproofing

FIGURE 1

An offshore oil and gas facility where industrial fireproofing is commonly used.

products as a function of the structural steel geometry used. Once the certification is achieved, the user can rest assured that the fireproofing product will perform in its intended environment.

There are two basic types of industrial fireproofing—cementitious and epoxy intumescent. Cementitious fireproofing is a cement-based material that provides fire protection through its inherent insulative properties. Epoxy intumescent fireproofing has the appearance and application characteristics of a protective paint or coating. Under the extreme temperatures of a fire, they activate and intumesce to produce a char layer that provides thermal protection for the steel. Both types are recognized as equally effective by the certifying bodies and the industry as a whole.

This supplement to *Materials Performance* presents a discussion of the different types of passive fireproofing materials that are utilized by the industrial and petrochemical industries, the performance that these materials can provide while in service, and the common usage and benefits of each. It addresses many common misperceptions, or "myths," in the industry regarding the performance and longevity of these materials and provides realistic explanations for each.

This article will address the myths concerning:

- The durability of cementitious fireproofing long term
- Relevance of moisture absorption of PFP materials
- The role of industrial PFP materials for corrosion protection
- The variable spray-applied density of epoxy PFP materials

Once the certification is achieved, the user can rest assured that the fireproofing product will perform in its intended environment.

Background

For many years, dense concrete was the primary fire protection material commonly utilized to protect structural steel in the refining and petrochemical industries. To this day, dense concrete continues to have a significant place in the industry, although proprietary high-density cementitious materials and epoxy-based intumescent passive fire protection (PFP) materials are now more commonly used.[3] The main reason for this shift in technology is primarily due to weight savings that cementitious and epoxy materials can provide and the overall physical and mechanical performance advantages these products offer. In many instances, cementitious and epoxy-based PFP products are the material of choice because many major projects are utilizing off-site, fabricated modules for plant construction. The use of off-site fabrication requires rugged, highly durable products that can resist damage during transit and construction. Cementitious and epoxy-based PFP products also offer the advantages of low weight, which minimizes transportation and construction costs and lowers the overall weight load on the structure (Figure 2).

Cementitious fireproofing products were originally developed to provide a lighter-weight, lower-density alternative to dense concrete. These materials provide a durable, efficient fireproofing solution that can be installed with minimal surface preparation requirements. They are primarily used for land-based petrochemical applications to provide fire protection for structural steel and to upgrade the fire resistance of existing concrete. These are powdered materials that are mixed with water to create a slurry that can be spray or trowel-applied to the

FIGURE 2

Cementitous PFP shop-applied to steel I-section in contour design and loaded on trucks to be transported to site.

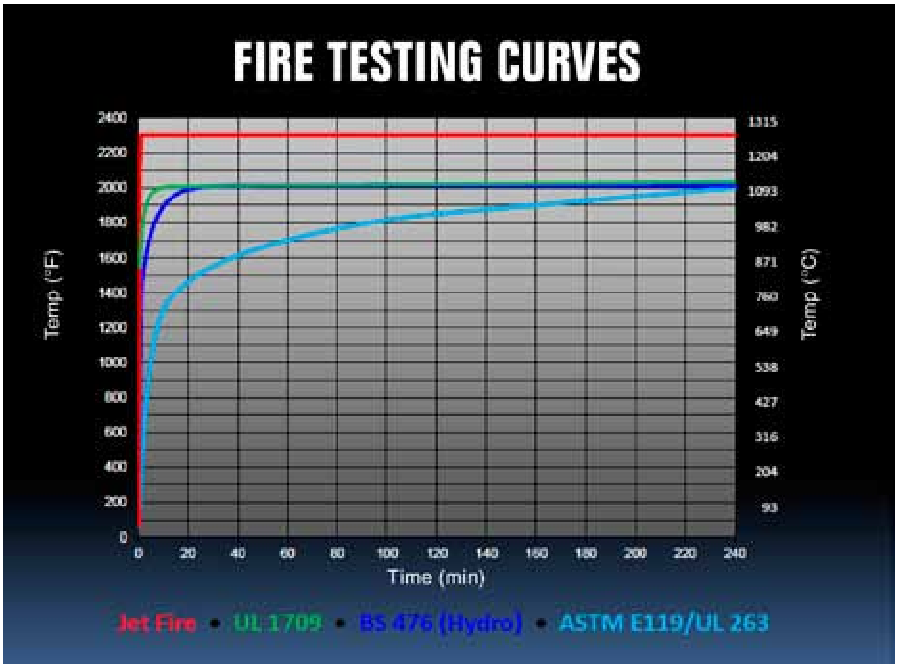
FIGURE 3

Steel columns coated with epoxy PFP material exposed to UL 1709 hydrocarbon fire testing.

substrate. They are designed to provide fire protection for structural steel in industrial facilities. Cementitious fireproofing works by encasing and insulating the steel, keeping the steel temperature below the critical failure point for a given amount of time depending on the thickness applied. These materials are well suited for land-based applications. They provide a low-cost alternative to epoxy intumescent fireproofing and a lightweight alternative to dense concrete.

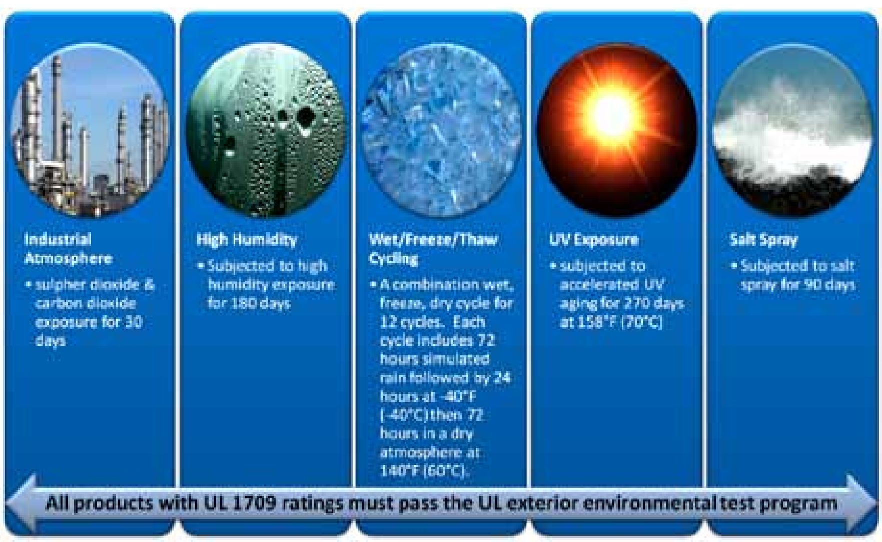
Cementitious fireproofing materials are well suited for land-based applications. They provide a low-cost alternative to epoxy intumescent fireproofing.

FIGURE 4



Industrial fire testing exposures. Jet fire test exposures are indicative time/temperature relationships.

FIGURE 5



Summary of UL 1709 environmental test program.

Epoxy intumescent coatings have been used in petrochemical and offshore facilities for many years. The first generation of epoxy intumescent PFP materials was introduced over 30 years ago. These materials were originally developed to provide an efficient fire protection solution for the onshore petrochemical industry. Over time these materials have become an industry standard for the protection of structural steel for both onshore petrochemical and offshore oil and gas assets due to their combined durability, weathering resistance, and fire protection.[2]

Both cementitious and epoxy intumescent materials are used to protect petrochemical processing facilities from fire and prevent the escalation of a fire event, which may occur from the rupture or failure of critical piping, adding fuel to the blaze. Areas used as points of egress are typically protected as well to provide the time needed to evacuate personnel and protect assets from collapse during a hydrocarbon fire and/or jet fire event. These materials can provide the same level of fire protection, excellent weathering characteristics, high physical performance, long-term durability, and weight savings.

The level of protection required is dependent on the size, mass, and configuration of the steel section. The level of protection provided by a PFP material is dependent on the efficiency of the material and the thickness applied. These systems are used to prevent steel structures from reaching the temperatures at which the structure will begin to fail. This is known as the limiting temperature.

Generally, the lower the limiting temperature required for a structure, the higher the thickness requirements will be to protect that structure.[3]

Testing Standards

PFP materials must have proven performance when subjected to the harsh environmental conditions and the extreme heat of hydrocarbon pool fire and jet fire exposures.[2] They must undergo rigorous fire, environmental, and physical property testing to industry-accepted standards. In addition, they must be certified and have type approvals by internationally recognized certification bodies. Quality audits by these certification organizations ensure high-quality material production and good long-term performance. Certification ensures that the material has been tested to an internationally recognized and accepted test standard. This allows the specifier or customer to compare various products and technologies with the confidence that they will perform while in service.

Onshore Fire Testing

For cementitious and epoxy materials to be classified for land-based petrochemical use, they must meet hydrocarbon testing requirements for land-based applications. Two main hydrocarbon test standards that are commonly used in many parts of the world are the Underwriter's Laboratories (UL) 1709, "Rapid Rise Fire Tests of Protection Materials for Structural Steel,"[4] and the ISO 834/BS-476 Hydrocarbon Fire Curve.[5-6] There may be other specific testing standards depending on the country, but the UL 1709 and ISO 834/BS-476 are the most uniformly recognized. These test standards were developed with significant input from the major oil and gas producers and engineering firms and are now accepted as industry standards for land-based petrochemical applications in many parts of the world.

Rapid rise hydrocarbon fire testing simulates fuel burning at atmospheric pressure that would result from the rupture of a storage vessel, piping, or valve, creating a "pool" of burning hydrocarbon fuel. In the UL 1709 test, the furnace reaches a temperature of 2,000 °F (1,093 °C) in the first five minutes and maintains this temperature for the duration of the test (Figure 3).[4] In the ISO 834/BS-476 test, the furnace reaches a temperature of 2,000 °F in the first 20 minutes and maintains this temperature for the duration of the test.The UL 1709 fire exposure program is perceived to be the most stringent hydrocarbon test in the industry. It is a requirement in many parts of the world for products used in onshore petrochemical and oil and gas applications where there is a potential for a hydrocarbon fire. The difference between these two fire curves are illustrated in Figure 4.

Certification allows the specifier or customer to compare various products and technologies with the confidence that they will perform while in service.

The UL 1709 test program includes both fire testing and environmental testing for the products being evaluated. All cementitious and epoxy materials that are classified under the UL 1709 program and possess UL designs must undergo the same fire and environmental testing.

Onshore Environmental Testing

For cementitious and epoxy intumescent materials to be classified for use in onshore, land-based applications, they must also pass the UL 1709 environmental test program. This test program simulates a long-term weathering exposure in onshore industrial environments and is considered a global standard for the petrochemical industry. Products that can pass this program give complete confidence that the fire performance of the material will remain intact even when subjected to long-term environmental extremes. This test program verifies the performance and ensures the durability of the industrial PFP material.[2] After the environmental cyclic testing, the test samples are subjected to fire testing and compared to non-exposed control samples to verify long-term fire performance of the material (Figure 5).[4]

UL 1709 Environmental Test Summary

Sample Preparation

- The fireproofing system is applied at the material's 60 to 90-minute rating thickness (thickness can vary from product to product depending on the material's thickness requirements).
- Testing is performed with reinforcement (if necessary).
- Testing is performed on the materials with a topcoat.
- The dimensions of the fire test columns are 6 in x 6 in x 2 ft (300 mm x 300 mm x 1.2 m) square tubes with a wall thickness of 3/16 in (4.7 mm).

Test Parameters

- Industrial atmosphere: sulfur dioxide (SO_2) and carbon dioxide (CO_2) exposure for 30 days
- High humidity: subjected to high humidity exposure for 180 days
- Wet/freeze/thaw cycling: a combination wet, freeze, dry cycle for 12 cycles. Each cycle includes 72 h simulated rain followed by 24 h at –40 °F (–40 °C), then 72 h in a dry atmosphere at 140 °F (60 °C)
- Ultraviolet (UV) exposure: subjected to accelerated UV aging for 270 days at 158 °F (70 °C)
- Salt spray: subjected to salt spray for 90 days

Pass/Fail Criteria

- After the material samples have been subjected to the cyclic testing, they are fire tested and compared to non-aged control samples to verify fire performance.
- The aged samples must perform within 75% of the fire endurance compared to the control samples.

All products with UL 1709 ratings must pass all aspects of the UL exterior environmental test program. This testing protocol is identical for both cementitious and epoxy intumescent PFP products.

TABLE 1

Comparison of industrial PFP fire test standards

Test Program	Hydrocarbon (UL 1709)	Hydrocarbon (ISO 834 / BS-476)	Jet Fire (ISO 22899-1)
Environment	Onshore	Onshore/offshore	Onshore/offshore
Direct Impingement	Yes	No	Yes
Erosive force	Low	Low	High
Steel tested	W10 x 49 "I" section	Range of steel sections	Web, hollow section, box
Limiting temperature	1,022 °F (550 °C)	1,000 °F (538 °C)	752 °F (400 °C) max. (typical)
Heat flux (kW/m²)	200	200	250 to >300

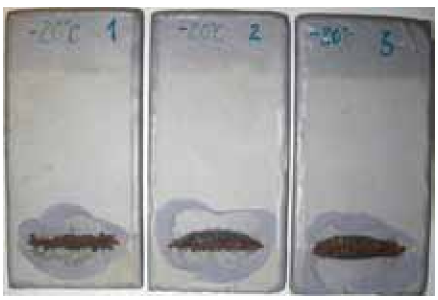
FIGURE 6

PFP material being subjected to ISO 22899 jet fire test.

FIGURE 7

Images of NORSOK M-501 aging panels coated with epoxy PFP material with scribe after 4,200 h in the aging resistance test.

FIGURE 8



Images of NORSOK M-501 aging panels coated with epoxy PFP material after scraping the scribed area to measure corrosion creep under PFP system.

Each product must successfully pass this testing protocol in order to obtain UL 1709 exterior fire ratings.

All materials that pass the UL 1709 test program have been subjected to stringent environmental and subsequent fire testing to verify performance. This ensures that the fire rating will remain intact throughout the life of the coating. The UL 1709 environmental test program is designed to simulate the actual environments that PFP materials are subjected to in service. This test method has been fully vetted by multiple industry authorities for many years. It is the recognized assessment method for evaluating environmental exposure. The UL environmental protocol does not involve immersion testing for good reason. Industrial PFP materials are used for atmospheric exposures and not immersion service.[4] The effects of immersion testing are misleading and should be considered irrelevant for this service environment.

The UL environmental protocol does not involve immersion testing. The effects of immersion testing are misleading and should be considered irrelevant for this service environment.

Offshore Fire Testing

For PFP materials to be classified for offshore use they must meet two main fire-testing requirements that are commonly accepted. These are hydrocarbon pool fire and jet fire exposures. The main differences between these test procedures are detailed in Table 1.

The accepted requirement for the hydrocarbon pool fire testing for the offshore industry is the ISO 834/BS-476 hydrocarbon curve. In this test, the furnace reaches a temperature of 2,000 °F in the first 20 minutes and maintains this temperature for the duration of the test. Testing for hydrocarbon fire exposures is required for both onshore and offshore oil and gas applications where there is a potential for a hydrocarbon fire (Figure 4).

Jet Fire Testing

Jet fire testing simulates a ruptured riser pipe, vessel, or valve that is releasing hydrocarbon fuel under pressure at sonic velocities. This is by far the most severe type of fire environment as the force of the fire torch has direct impingement on the sample, producing an erosive force that must be withstood by the fire protection system. Jet fires have a significant erosive force, and higher heat fluxes than hydrocarbon pool fires. The industry-accepted standard for jet fire testing is ISO 22899-1 (Figure 6).[7] This test simulates natural gas jet fires that could occur on offshore platforms and land-based facilities, where hydrocarbon fuel leaks can produce significant heat flux to structural steel. The test sample is instantaneously subjected to 2,300 °F (1,260 °C) (Figure 4). Jet fire testing is a requirement that is used predominantly for the offshore industry but is also applicable for onshore facilities where flammable hydrocarbon materials are processed under pressure. The potential for jet fire exists wherever storage, process equipment, or piping contains flammable natural gas under high pressure.

FIGURE 9

Image of NORSOK M-501 aging panel coated with epoxy PFP material after 4,200 h in the aging resistance test prior to fire testing.

Offshore Environmental Testing

For epoxy intumescent materials to be classified for use on offshore facilities, it is recommended that they pass the NORSOK M-501 System 5A[1] environmental test program. This test program simulates a long-term exposure to harsh offshore environments and is the accepted global standard for the offshore industry. Products that can pass NORSOK M-501 System 5A give complete confidence that the fire performance of the material will remain intact even when subjected to these harsh weather extremes. This test program verifies epoxy intumescent performance without a topcoat and ensures that the system provides corrosion protection as well. After the environmental cyclic testing, the test samples are subjected to inspection of corrosion creep, adhesion testing, and fire testing to verify long-term material performance (Figures 7 through 9).

NORSOK M-501 System 5A Environmental Test Summary

Sample Preparation

- The thickness of the system is 6 mm (240 mils).
- The system includes a primer and PFP without reinforcement.
- Testing is performed on the system with and without a topcoat.
- The dimensions of the fire test plates are 6 in x 6 in (300 mm x 300 mm) and are unscribed.
- The dimensions of the corrosion test plates are 3 in x 3 in (75 mm x 150 mm) with a 0.08 in x 2 in (2 mm x 50 mm) scribe cut through the coating into the metal substrate.

Test Parameters

Samples are subjected to accelerated aging resistance testing performed according to ISO 20340[8] for 25 cycles. Each cycle lasts one week (168 h) and includes the following:

- 72 h of exposure to UV and condensing water in accordance to ISO 11507[9]
- 72 h of exposure to neutral salt spray in accordance to ISO 7253[10]
- 24 h of low-temperature exposure at –20 °C

Pass/Fail Criteria

NORSOK M-501 acceptance criteria for aging resistance-tested samples, system 5A:

- Corrosion creep must be ≤3 mm (120 mils).
- Pull-off adhesion strength is according to ISO 4624,[11] max. 50% reduction and min. 3.0 MPa.
- Two out of three panels must meet these requirements in order to pass.
- Water absorption after completing the aging resistance is reported. Water absorption is determined as the percentage weight increase during the 4,200-h test.[1]

NORSOK M-501 acceptance criteria for fire testing samples, system 5A:

- After the material samples have been subjected to the accelerated aging testing, the samples are fire tested and compared to non-aged control samples to verify fire performance.
- Both panels are fire tested for 60 minutes. The mean temperature of each plate is then mesaured after 60 minutes.
- The aged sample plates are allowed a maximum 10% increase in mean temperature as compared to the simultaneously tested non-aged reference plate.
- This requirement refers to the mean temperature increase from the two plates when fire tested for 60 minutes or when the plate exceeds 752 °F (400 °C) within 60 minutes of the fire test.

Explosion Testing

Explosion testing is designed to evaluate an industrial PFP material's ability to remain intact after an explosion. The true measure of a material's ability to resist explosion is overblast testing. This type of testing subjects PFP-coated steel to the force of an explosion by using a high-pressure airblast that causes a deflection to occur. Industrial PFP materials must be able to successfully resist the deflection of the overblast test with no cracking or delamination.

FIGURE 10

Bulkhead coated with epoxy intumescent PFP after explosion testing showing permanent deflection with no cracking or delamination.

FIGURE 11

PFP material being subjected to hose stream test while exposed to hydrocarbon fire.

This ensures the material will stay in place and perform during an explosion followed by a hydrocarbon pool fire or jet fire event (Figure 10).

Hose Stream Testing

Hose stream testing is utilized to demonstrate a material's robustness and integrity during a hydrocarbon fire and the ability of the PFP material to remain intact and perform while being subjected to the force of a fire hose. The purpose of this test is to evaluate whether a PFP material can hold in place and continue to perform and protect the steel structure while the fire is being fought. Materials that can pass this testing ensure the material can perform its intended function while the fire is being extinguished or if a secondary explosion and fire occur (Figure 11).

The high insulation properties of industrial cementitious PFP materials make them excellent insulators. Many of these materials can provide combined cryogenic and fire protection.

Cryogenic Testing

Cryogenic testing was developed to evaluate an industrial PFP material's ability to protect steel against embrittlement during a cryogenic spill in liquid natural gas (LNG) installations and other cryogenic facilities. The goal is to develop industrial PFP systems that can provide combined cryogenic and hydrocarbon fire protection in one system. This type of test subjects the PFP-coated steel to a cryogenic liquid (liquid nitrogen) and measures the temperature of the steel surface. The high insulation properties of industrial cementitious PFP materials make them excellent insulators. Many of these materials can provide combined cryogenic and fire protection. Epoxy intumescent materials, on the other hand, are generally poor insulators and some type of insulative coating must be installed underneath the fireproofing system in order to provide a combined cryogenic and fire protection system (Figure 12).

Certification

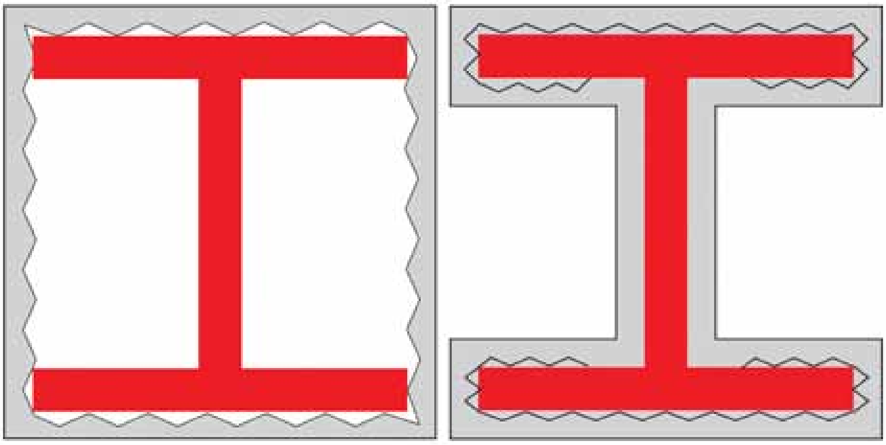
The testing of PFP materials is generally carried out at a third-party test facility such as Intertek, UL, Southwest Research Institute, Sintef NBL, Exova Warrington Fire, and others. Tests are conducted in accordance with industry-accepted standards. In addition, this testing must be witnessed and approved by a certifying organization in order to receive the certification required by industry. These certification bodies are organizations such as UL, Lloyd's Register of Shipping (LRS), Det Norske Veritas (DNV) and American Bureau of Shipping (ABS).[2]

Risk assessments must be performed to ensure that the correct level of fire protection has been specified and installed. Insurers of the assets will require that fire protection materials are certified by recognized certification bodies to ensure the correct level of fire protection is implemented. These organizations witness the manufacture of these materials to verify that the material is produced consistently and witness all testing to verify it is conducted to industry standards. They will then analyze the test results and provide ratings that can be used for the fire protection of steel structures. Use of standard test methods and third-party certification ensures that the PFP materials will perform properly.

FIGURE 12

High-density cementitious PFP material during cryogenic exposure.

FIGURE 13



Box and contour configurations of cementitious PFP materials. The use of box designs reduces the surface area to be fireproofed by 30%.

Installation and Properties

Cementitious PFP

Cementitious PFP materials can be installed in either box or contour configurations. Installing cementitious PFP materials in a box configuration reduces the surface area to be fireproofed by approximately 30%. This reduces the amount of material required and significantly reduces the labor required to install. In contrast, epoxy PFP materials can only be installed in a contour configuration (Figure 13).

Industrial cementitious materials typically have densities ranging from 40 lb/ft^3 (PCF) to 55 PCF (640 to 881 kg/m^3). The 55 PCF density materials are classified as "high density," while the 40 PCF (640 kg/m^3) materials are considered "medium density" products.[12] The high-density materials will always have increased physical performance and higher durability, but will have lower coverage due to their higher density. The medium-density materials are considered to be a lower-cost alternative with higher coverage rates, but will sacrifice physical and mechanical performance due to the decrease in density. Both types are suitable for land-based industrial applications. The choice of whether to use a high-density or medium-density material will depend on the project requirements and physical performance specifications.[12]

Properties

- These products typically have UL 1709 and/or ISO 834/BS-476 hydrocarbon ratings.
- They provide a low-cost alternative to epoxy intumescent materials and are generally half the installed cost of epoxy intumescents.
- Cementitious PFP is a lightweight alternative to dense concrete and is generally one-tenth the installed weight of dense concrete.

FIGURE 14

High-density cementitious PFP applied to sphere legs in petrochemical facility.

FIGURE 15

Cross section of I-beam after intumescent reaction showing heat-blocking char layer.

FIGURE 16

Mesh reinforcement being installed into wet epoxy intumescent PFP.

- The installation of these materials can be done using either contour or box designs. Contour designs will provide the highest long-term durability, while box designs are better suited for in-place applications. Box designs can reduce the surface area that is required to be fireproofed by up to 30%.
- Typically they are mechanically attached to the steel with metal lath and mechanical fasteners, although there are some ratings both with and without lathe.
- There is no topcoat requirement to pass the UL 1709 environmental program. However, cementitious PFP materials can be topcoated to improve overall performance.
- Cementitious fireproofing materials can be formulated to provide hydrocarbon pool fire, jet fire protection, and cryogenic protection. Some materials can provide all of these types of protection at the same thickness.
- These materials are well-suited for both shop and field-applied projects.

Types of Uses

Cementitious PFP materials are used in onshore facilities such as refineries, LNG facilities, power plants, and industrial manufacturing facilities, and petrochemical plants (Figure 14). They provide both hydrocarbon pool fire and/or jet fire ratings (dependent upon product type) for structural elements, beams, columns, bulkheads, and LPG vessels. They can also be used for upgrading the fire resistance of existing concrete.

Keys to Success

The density of cementitious PFP materials is crucial to obtain the specified level of fire protection and physical performance. Generally, the higher the density of a cementitious material, the higher the physical properties and fire performance. The density will also affect the coverage of the material. The cured density of cementitious PFP materials must fall within the tested range stated in the fire test design. The density of cementitious materials can be affected by water levels, mixing times, and application techniques.

Always follow the manufacturer's written application instructions. If primers are required, prepare the steel according to the primer specifications. Install all lath

TABLE 2

Comparison of epoxy intumescent PFP materials (based on UL 1709 program)

Product	Thickness in mils (mm)				Jet Fire Protection Ranking
	1 h	1 ½ h	2 h	3 h	
Brand A	120 (3)	210 (5.3)	310 (7.8)	500 (12.7)	2
Brand B	NR	400 (10.1)	600 (15.4)	NR[A]	1
Brand C	228 (5.7)	324 (8.2)	421 (10.7)	615 (15.6)	4
Brand D	280 (712)	400 (10.1)	520 (13.2)	750 (19.0)	3

[A]NR means no rating is available

Note: All thicknesses are shown in inches and are based on a W10 x 49 column size.

tight to the steel and according the specific design detail. When mixing cementitious PFP materials, use a mortar mixer with rubber tip blades. Add the correct water amounts and mix according to the manufacturer's written specification. Perform density checks at least twice daily to ensure that the correct density is being achieved.

Even though these are exterior-rated products, they still must be installed in the correct environmental conditions and protected from rain and running water for at least 24 h after final application. Always apply the full material thickness within the manufacturer's stated application window and in the correct thickness per coat to ensure proper bonding of the material to the substrate and between coats. All terminations should be sealed with caulk to prevent water ingress.

PFP materials must be properly installed and maintained to have a successful service life. Cementitious PFP materials are meant to be a low-maintenance coating designed to last for the life of the asset if installed and maintained correctly. These materials should be included in the planned inspection program of the facility. Typical maintenance items include:

- Routine inspection of the cementitious PFP system
- Maintain caulking at all terminations
- Repair of any breaches in the system
- Repair of any disbonded or delaminated areas
- Repair of any topcoat failures, delamination, or disbondment

Epoxy Intumescent PFP

Epoxy intumescent coatings are two-component, 100% solids (solvent free) epoxy materials that are designed to provide hydrocarbon and/or jet fire protection for structural steel elements. These materials are designed to provide passive fire protection. Under normal conditions these coatings are inert or "passive" like other paint-like coatings. When exposed to the extreme heat of fire, these coatings begin to intumesce or expand, forming a thick heat blocking char layer. This heat blocking char provides an insulating layer that protects the steel from reaching the critical failure temperature for a given amount of time (Figure 15). Epoxy PFP coatings are well-suited for both onshore and offshore (depending on the product type) and are typically specified where higher physical performance and lower weight restrictions are required.[12]

Epoxy PFP materials that are formulated to have better jet fire performance with ISO 22899 will sacrifice fire performance in the UL 1709 test program.

FIGURE 17

Epoxy PFP installed to structural supports on an offshore facility.

FIGURE 18

Epoxy intumescent PFP being shop-applied to structural steel.

The density of all current epoxy intumescent materials is close to 1.3 g/cm³ (in the can). The spray-applied density of epoxy intumescent materials can vary from 1.0 to 1.2 g/cm³ depending on how the materials are applied.

TABLE 3

Physical comparison of industrial PFP materials—selecting the right product depends on the project parameters

Industrial PFP System Comparison (Typical Values)				
Material Type	**Dense Concrete**	**Medium-Density Cementitious PFP**	**High-Density Cementitious PFP**	**Epoxy PFP**
Environment	Onshore	Onshore	Onshore	Onshore/Offshore
Density	135 PCF (2.1 g/cm³)	40 PCF (0.6 g/cm³)	55 PCF (0.8 g/cm³)	62-74 PCF (1.0-1.2 g/cm³)[A]
Weight per rating	High	Medium	Medium	Low
Cryogenic protection	No	Yes	Yes	No[B]
Hydrocarbon protection	NR[C]	Yes	Yes	Yes
Jet fire protection	NR[C]	No	Yes	Yes
Hose stream endurance	Pass	Pass	Pass	Pass
Chemical resistance	Low[D]	Low[D]	Low[D]	High
Explosion resistance	High	High	High	High
Compressive strength	3,000 psi (20.6 MPa)	594 psi (4.1 MPa)	817 psi (5.6 MPa)	2,100 psi (14.5 MPa)
Flexural strength	400 psi (2.7 MPa)	136 psi (0.9 MPa)	502 psi (3.4 MPa)	2,200 psi (15.2 MPa)
Adhesion/cohesion	350-500 psi (2.4-3.4 MPa)	>7 psi (48 kPa)[E]	>8 psi (55 kPa)[E]	>300 psi (2.1 MPa)
Shore D hardness	>90	40	55	>50
Shipping cost	Highest	Lower	Lower	Lowest
Shop applied cost/ft²[F]	$8-10	$15-25	$15-25	$35-50
Field blockout cost/ft²[F]	$115-120[G]	$30-40	$30-40	$50-60

[A] Spray-applied density can vary with material temperature, pressure, and application technique.
[B] Cryogenic protection is only provided with epoxy syntactic insulation under epoxy PFP.
[C] No ratings available, concrete has no UL 1709 or BS-476 listings although it is generally accepted for use by the industry.[1]
[D] Chemical resistance enhanced by applying chemical resistant topcoat.
[E] Cementitious materials are generally installed with mechanical attachment to the steel using metal lath and fasteners.
[F] Based on typical 2-h rating, costs can vary dependent upon application.
[G] Concrete field costs are extremely high due to the high cost of constructing the forms in place to pour the connection points.

Fireproofing materials can be formulated to have better performance in any fire endurance category. Materials that are designed to perform well in jet fire exposures must have better barrier properties to resist the erosive force that is generated in these types of fires. As a result, these epoxy intumescents will also have lower moisture absorption rates due to the nature of their formulation and higher resin content required for jet fire performance. Generally, epoxy PFP materials that are formulated to have better jet fire performance with ISO 22899 will sacrifice fire performance in the UL 1709 test program, meaning that well-performing jet fire epoxy intumescent materials will often require higher thickness than materials that were formulated to specifically meet UL 1709 (Table 2).

Properties

- These products typically have UL 1709 and/or ISO 834/BS-476 hydrocarbon and ISO 22899 jet fire ratings.
- These materials provide a lightweight option with increased physical and chemical resistance.
- Epoxy PFP materials have a higher installed cost than cementitious PFP.
- Compatible primers are critical for maintaining the adhesion of the epoxy PFP to the substrate. Improper adhesion will affect the long-term performance of the system. Not all primers are compatible. Only use manufacturer-approved primers and observe the minimum and maximum recoat windows.
- Current materials require mesh reinforcement for hydrocarbon and jet fire exposures. The mesh reinforcement adds enhanced weathering and fire endurance (Figure 16).
- Topcoats are generally required for the PFP system to pass the environmental testing and for UV stability.
- Epoxy PFP materials can provide hydrocarbon pool fire and jet fire protection.
- These materials are well-suited for both shop and field-applied projects (Figure 18).

FIGURE 19

Weathered test article placed in furnace to be fire tested after six years of weathering.

Typical Uses

Epoxy intumescent PFP materials are used in refineries, petrochemical plants, LNG facilities, power plants, industrial manufacturing facilities, and offshore facilities. They provide both hydrocarbon pool fire and/or jet fire ratings (dependent upon product type) for structural elements, beams, columns, bulkheads, underdecks, risers, and LPG vessels (Figure 17). They can also provide combined cryogenic and fire protection when used in conjunction with epoxy syntactic insulation materials. Epoxy PFP materials are commonly preferred for offshore facilities where added weight is a concern.[12]

Keys to Success

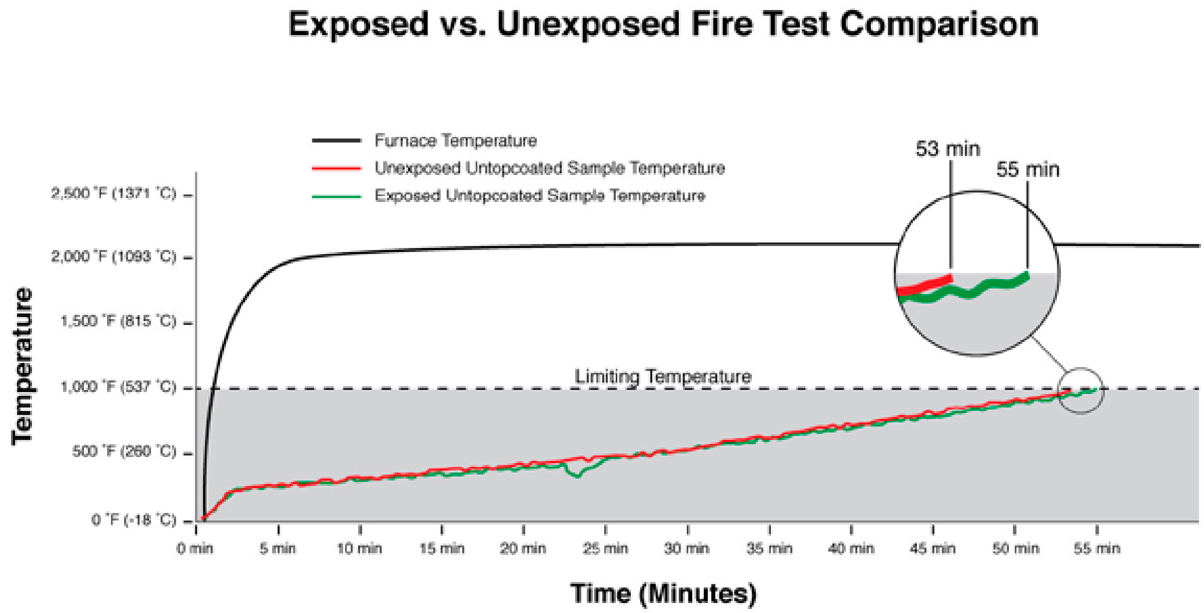
The density of all current epoxy intumescent materials is close to 1.3 g/cm^3 (in the can). The spray-applied density of epoxy intumescent materials can vary from 1.0 to 1.2 g/cm^3 depending on how the materials are applied. Temperature variations of the materials, differences in pressure, and spray techniques can greatly influence the spray-applied density of these materials. This in turn can greatly affect the coverage of the material. For this reason, spray-applied densities should be stated as a range and should be confirmed prior to application of these materials on a project.

All epoxy PFP materials are only as good as their application. The long-term performance of these materials is dependent upon proper installation of the PFP system in strict accordance with the manufacturer's written specifications. This includes proper surface preparation, application of approved primers, proper installation of the PFP system, and manufacturer-approved topcoats.

Epoxy PFP materials are meant to be low-maintenance coatings that are designed to last for the life of the asset if installed and maintained correctly.

The condition of the substrate is critical to maintaining the fire performance and fire rating. Substrates that are not properly prepared can lead to disbondment of the coating and loss of fire rating. Always prepare the surface according to the manufacturer's written instructions. Improper adhesion will affect the long-term performance of the system. It is critical to use a primer that is compatible with the industrial PFP material. Not all

FIGURE 20



Fire test results showing no effect to an untopcoated epoxy PFP product after six years of weathering.

primers are compatible. Only use manufacturer-approved primers and observe the minimum and maximum recoat windows.

These materials must be applied in the correct thickness per coat and within the stated application window following the manufacturer's written application procedures. These systems typically require multiple coats and must be applied at the required dry film thickness (DFT) to achieve the desired fire rating.

Epoxy PFP materials must be applied in good weather and within the manufacturer's stated application conditions. They must be protected from direct rain and running water until they have reached sufficient cure. If water contamination occurs, any uncured material must be removed and reapplied. The material must be clean and dry prior to applying subsequent coats or topcoating. All epoxies will chalk and fade over time. Because of this, all will require a topcoat for long-term UV protection and color coordination. Not all topcoats are compatible. Only use manufacturer-approved topcoats and observe the minimum and maximum recoat windows. The topcoat thickness required will depend on project specifications.

Epoxy PFP materials are meant to be low-maintenance coatings that are designed to last for the life of the asset if installed and maintained correctly. Typical maintenance items include:

- Routine inspection of the epoxy intumescent system
- Repair of any breaches in the epoxy intumescent system
- Repair of any disbonded or delaminated areas
- Repair of any topcoat failures, delamination, or disbonding

Life Expectancy

These are high-build coatings that generally exhibit high physical and mechanical properties. All industrial PFP materials are not the same when it comes to their durability and long-term performance. Epoxy intumescent and cementitious fireproofing that have higher physical properties will resist damage better during construction and will have superior performance throughout the life of the asset.

These materials have been designed to have robust weathering characteristics and perform in the harshest environments. Epoxy intumescent and cementitious PFP materials have been successfully used for over 30 years for onshore and offshore applications around the world. If installed correctly and properly maintained, these materials can have a life expectancy ranging from 20+ years to the life of the asset.

Dispelling the Myths

Myth #1: Are Cementitious PFP Materials Durable Long Term?

Cementitious PFP materials have been successfully specified and used by major engineering firms, petrochemical facilities, and refineries for over 30 years. There are literally hundreds of millions of square feet of steel protected with cementitious PFP around the world.

Cementitious PFP materials have been proven to have high physical performance and when properly maintained, can last the lifetime of the asset. These materials have been tested for a variety of environmental and fire exposures and have proven performance in actual real-world hydrocarbon fires.

Current cementitious PFP formulations are inert and do not promote or prevent corrosion. They should not be considered as part of the corrosion protection system. This is provided by the corrosion-resistant primer system or galvanized surface. Many years ago, older cementitious technologies contained magnesium oxy chloride, which was found to cause corrosion in the presence of water. This compound is no longer used in current materials.

Myth #2: Does Moisture Absorption Affect an Epoxy PFP Material's Performance?

The true measure of environmental resistance of an industrial PFP material is through analyzing the material using a vetted, industry-accepted environmental test program. Immersion testing is not a meaningful way to determine long-term performance of intumescent PFP. The correct testing for moisture absorption with these materials is what is reported in the test program. In order for an industrial PFP material to be deemed suitable for a particular environment it must be evaluated to a proper environmental testing program. These industry standards have been established to properly test materials to environmental extremes and be able to evaluate their performance on a level playing field. A material that can pass the UL environmental test program and retain its fire properties is classified by UL as an exterior product that can withstand the harsh conditions present in land-based petrochemical and industrial applications.[3] If an epoxy intumescent system can successfully pass the NORSOK M-501 test program, it is accepted to be suitable for offshore use.

Epoxy intumescent coatings are not meant for immersion service. These products are designed to be atmospheric coatings applied to structural steel and not exposed to total immersion conditions. There are epoxy PFP manufacturers that report results of placing un-topcoated samples in immersion in water, which is misleading the industry and has no correlation to actual product performance.

In order to evaluate the true effect of moisture absorption, a study was conducted to test epoxy PFP materials after being exposed to atmospheric weathering conditions for six years without a topcoat. The test program compared the exterior weathered, untopcoated samples to samples that were left unexposed to weather.

All test articles were applied at the same time. The steel was grit blasted to NACE No. 3/SSPC-SP 6[13] with a 1.5 to 2 mils (38 to 50 μm) profile. The steel plate was then applied with 3 mils (76 μm) DFT of a two-component epoxy primer. After a 24-h cure, all plates were spray-applied with an epoxy PFP material using plural-component, hot spray, airless equipment to a nominal thickness of 280 mils (7.1 mm). After final cure, the panels were placed on a weathered exposure rack for six years.

Immersion testing is not a meaningful way to determine long-term performance of intumescent PFP.

Once exposed, the sample was fire tested to a time/temperature curve consistent with the UL 1709 fire testing procedure (Figure 19).

An identical plate, acting as a control, was also fire tested in the same manner as the exposed test article. The control plate was applied at the same time as the exposed sample; however, it was maintained at laboratory conditions until fire tested. The applied thickness measured 283 mils (7.2 mm) DFT. The fire test comparison is shown in Figure 20.

The samples were fire tested after the six-year exposure. Based on the fire testing information derived from this investigation, it was found that the non-topcoated epoxy PFP samples retained their fire properties with no loss in fire protection after being exposed to natural weathering cycles for six years.

Myth #3: What Role Does Industrial PFP Play in Corrosion Protection?

Today's industrial PFP materials do not promote corrosion nor are they designed to provide corrosion protection by themselves. The corrosion protection is provided by the corrosion-resistant primer or primer system. The NORSOK M-501 and UL 1709 environmental test programs require an approved primer for this reason. Epoxy primers, organic zinc-rich epoxy primers, or inorganic zinc/polyamide tie-coat primer systems are typically utilized for corrosion protection.[17] Industrial PFP materials are formulated to provide fire protection and do not prevent corrosion without a primer system underneath.

Myth #4: Does Spray-Applied Density of Epoxy PFPs Vary?

As stated previously, the density of all current epoxy intumescent materials are close to 1.3 g/cm^3 (in the can).

The spray-applied density of epoxy intumescent materials can vary from 1.0 to 1.2 g/cm^3 depending on how the materials are applied. Temperature variations of the materials, differences in pressure, and spray techniques can greatly influence the spray-applied density of these materials. The differences in the spray density can then greatly affect the coverage of the material.

FIGURE 21

Epoxy intumescent PFP applied to steel in shop with "block-outs" for field connections.

For this reason, spray-applied densities should be stated as a range and should be confirmed prior to application of these materials on a project.

The non-topcoated epoxy PFP samples retained their fire properties with no loss in fire protection after being exposed to natural weathering cycles for six years.

Choosing the Right PFP

Not all industrial PFP materials are created equal. Different materials will have varying thickness requirements to achieve the desired hydrocarbon or jet fire ratings. In order to compare these products you must analyze them based on the following criteria:

- **Thickness comparisons**: This must be based on project-specific hourly ratings. The lower the thickness requirement, the less material required to achieve an equal fire rating. Because of this disparity in fire performance, there are materials that require up to 40% less thickness to provide the same level of hydrocarbon fire protection. Epoxy intumescent products that have higher efficiency, requiring less thickness for equal fire rating, will generate material and labor savings as well as significant weight reduction on the overall structure. However, the PFP materials that are the most efficient for hydrocarbon fire protection (according to UL 1709) may not provide the best jet fire protection. Table 2 presents a comparison of different products.
- **Physical comparisons**: You get what you pay for. Products with higher physical performance attributes and better fire endurance properties may require an upgrade in cost.
- **Installation costs**: When figuring the installed cost for a project you must factor in all material and labor costs to apply, and the transportation costs (if applied in the shop) (Figure 21). Hidden costs will include things such as the cost of applying material to the blockouts in the field. Field blockouts are the areas that are left non-fireproofed in the shop to allow for connection points in the field. The field blockout cost is the material and labor cost to apply the PFP to the connection points. Heavier materials will require more shipments with less coated steel sections per load, which can drastically increase the overall installed cost for shop-applied projects.
- **Installed weight per fire rating**: The thickness required to achieve a fire rating and the weight of the material itself will determine the total installed weight of the PFP material. Lower thickness translates into less overall weight, which will reduce the overall load on the structure.

The selection of the optimum PFP material for a particular application is highly dependent on the parameters of the project. Questions such as where the application will take place, what type of fire protection is needed, and what type of application equipment is necessary are critical when selecting the right product. A summary of parameters as a function of PFP type is shown in Table 3.

There are literally hundreds of millions of square feet of steel protected with cementitious PFP around the world.

Conclusions

The onshore petrochemical and offshore oil and gas industries have established stringent test standards and certification requirements for industrial PFP materials with the adoption of UL 1709, ISO 22899, ISO 834/BS-476, and NORSOK M-501. These standards have been fully vetted by the industry and have been found to be predictive and consistent. These standards can be used to compare various PFP products with confidence. Our industry is better served by the elimination of deceptive practices that introduce uncertified, nonstandard testing that contradicts the industry standards.

As the technology is refined and the performance continues to improve, these technologies continue to provide reduced thickness requirements and higher physical performance. The reduction in thickness directly translates to cost savings to install these materials and weight savings for the entire structure being protected. Newer generations of industrial PFP materials will continue to improve the durability and efficiency of these systems, resulting in materials that can resist the most severe climates on earth and provide reliable hydrocarbon and jet fire protection for high-risk environments.

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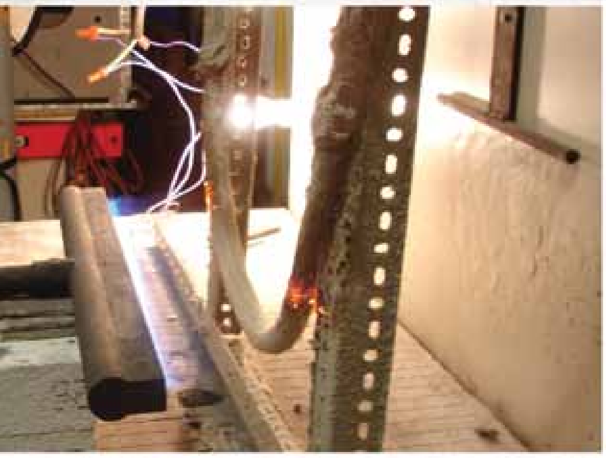

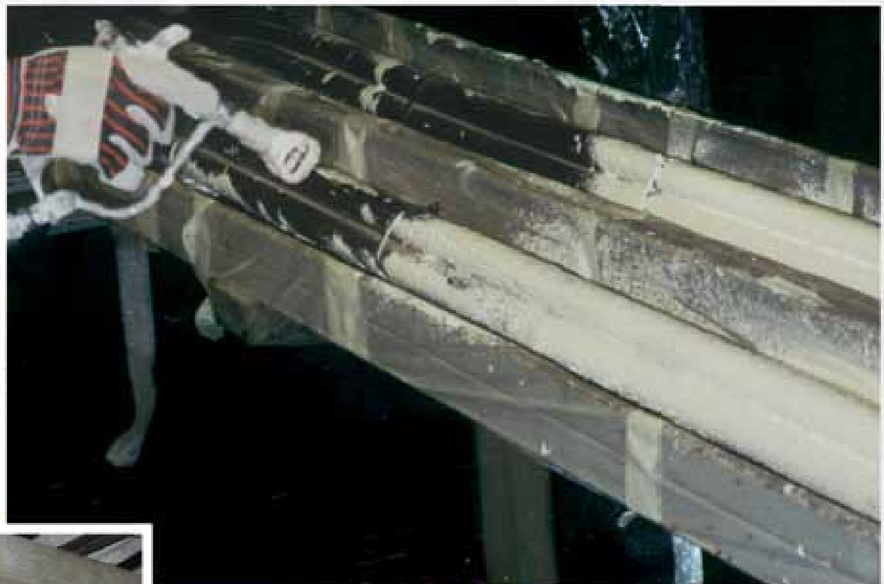

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