Today most buildings and structures have some degree of fire protection in order to protect lives, delay possible structural collapse allowing for evacuation, provide areas of temporary refuge in the case of fire, and ensure the integrity of escape routes by preventing or delaying the escalation of a fire and protect high-value assets.

There are two basic types of fire protection: active and passive. Active fire protection includes alarms and detection systems, sprinklers and water deluge systems, firefighting equipment and foam and powder extinguishers. Passive fire protection involves components of structural methods and materials such as concrete, mineral fiber boards, vermiculite cements and intumescent coatings. This article will describe how intumescent coatings can achieve passive fire protection in many structure types including offshore constructions, ships and commercial buildings.
Intumescent coatings have been used to protect the steelwork in buildings and other structures from fire for approximately 40 years. These coatings work by swelling up in the event of fire and physically creating a barrier between the steel and the fire for up three hours. Steel loses its structural strength at about 500°C and these coatings can delay the time it takes to reach this temperature (Fig. 1). Intumescents are often referred to as intumescent coatings. 

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Fig. 1: This graph illustrates the effect of intumescent coating on steel temperature in a hydrocarbon fire.

Fig. 2: This graph compares the heat-up rate of cellulose and hydrocarbon fires.
to as thin-film or thick-film coatings. Thin-film intumescents can be solvent- or water-based products and have dry film thicknesses (DFTs) of less than 5 millimeters. Thick-film coatings are typically solvent-free, epoxy-based with DFTs of up to 25 millimeters. Thick-film epoxies can also be used to form castings, typically in two half-shells to protect narrow diameter pipework where spraying would create large volumes of overspray.

The acceptance and use of intumescent coatings increased dramatically in Europe in the 1970s as the major oil companies learned of their ability to protect structural steel from the extreme heat caused by hydrocarbon fires, including jet fires caused by leaking hydrocarbons.

In 1988 an explosion and subsequent oil and gas fires at the Piper Alpha, a North Sea oil production platform, resulted in the deaths of 167 people and £1.7 billion ($3.4 billion) in damage. The severity of this disaster, considered the worst offshore oil disaster at the time, prompted increased development and use of intumescent coatings for protection against hydrocarbon fires. The coatings developed tended to be thick-film coatings, often with mesh reinforcement.

Also, in the 1980s, exposed steel was used more prevalently in the design of commercial structures and high-rise buildings, increasing the use of thin-film intumescents which looked more like conventional paint and therefore could meet the aesthetic requirements of architects.

**How Do Intumescent Coatings Work?**

Intumescent coatings react to fire by expanding to form a carbon “char” with low thermal conductivity, which essentially forms an insulating layer reducing the rate of heat transfer and extending the time necessary to reach the critical failure temperature of the underlying steel.

It’s a complex chemistry incorporating the organic (coating) binder resin — typically an epoxy — and an acid catalyst, for example ammonium polyphosphate, which decomposes to yield a mineral acid. This acid reacts with a carbonic source, for example, pentaerythritol, to produce a carbon char. A spumific (foam-producing) agent, such as melamine, reacts with the acid source and decomposes, evolving into an inert gas which then expands the char. These are the basic reactions taking place, although more complex interactions also occur. For example, filler particles are incorporated into the formulation to act as nucleating sites or “bubble growth” sites and the resin binder plays a large part in softening and charring. Reinforcing mesh can be used to support the formed char.
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Cellulosic vs. Hydrocarbon Fires
A cellulosic fire has a fuel source composed mainly of cellulose — for example, wood, cardboard or paper. Hydrocarbon fires are fueled by hydrocarbon compounds and ignite and grow exceedingly fast, achieving high temperature almost immediately after ignition, greater than 1,000 °C in less than five minutes (fig. 2, p. 53). Cellulosic fires are slower to reach maximum temperature but may eventually reach or surpass the temperature of a hydrocarbon fire.

Hydrocarbon fires can reach temperatures higher than 1,000 °C in less than five minutes (Fig. 2, p. 53). A pool (hydrocarbon) fire is defined as a turbulent diffusion fire burning above a horizontal pool of vaporizing hydrocarbon fuel where the fuel has zero or low initial momentum. A jet fire is a turbulent diffusion fire resulting from the combustion of a fuel continuously released with high pressure.

Testing Intumescent Coatings
No two fires are the same. The conditions depend on the type and quantity of fuel, the availability of oxygen and ambient conditions. For reproducible product testing in the U.K. “standard” fires have been defined. British Standards BS 476 (parts 20 and 21) “Fire tests on building materials and structures” and EN 13381 (part 8), “Test methods for determining the contribution to the fire resistance of structural members” describe how intumescent coatings are tested with cellulosic fire exposure. Performance depends on coating thicknesses, the types of steel section, I sections, hollow sections and the section orientation, i.e., beam or column.

Thermocouples are used to measure furnace temperature and core steel temperature. Other test standards include UL 1709, “Rapid Rise Fire Tests of Protection Materials for Structural Steel” and EN 13381 (part 8), “Test methods for determining the contribution to the fire resistance of structural members” describe how intumescent coatings are tested with cellulosic fire exposure. Performance depends on coating thicknesses, the types of steel section, I sections, hollow sections and the section orientation, i.e., beam or column.

Table 1: Ratio of Surface Exposed to Fire and “Heat Sink”

<table>
<thead>
<tr>
<th>Hp/A (m⁻¹)</th>
<th>A/V (m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heated perimeter</strong></td>
<td><strong>Surface Area</strong></td>
</tr>
<tr>
<td>Perimeter in m</td>
<td>Surface Area in m²</td>
</tr>
<tr>
<td>Cross section area in m²</td>
<td>Volume in m³ (per linear meter)</td>
</tr>
</tbody>
</table>

UL 1709, “Rapid Rise Fire Tests of Protection Materials for Structural Steel” for hydrocarbon fire exposure, ISO 22899-1, “Determination of the resistance to jet fires of passive fire protection materials” and IMO Resolution A.754 (18), “Recommendation on Fire Resistance Tests for ‘A,’ ‘B’ and ‘F’ Class Divisions” for fire protection of decks, bulkheads and doors on marine vessels. It is not possible to test every variation, so the test results are analyzed to produce an assessment of performance.

Ensuring Durability
To protect steel in a fire a coating must be resistant to the environment and be intact at the time of the fire. Poor durability can lead to ineffective fire protection resulting in structural failure during a fire and expensive restoration afterwards. Poor durability can also lead to corrosion of the substrate, compromising structural integrity. To ensure durability of intumescent coatings the key ingredients — ammonium polyphosphate, melamine and pentaerythritol — are all sensitive to moisture and must be formulated carefully.

Different resins are used to formulate intumescent coatings for different applications. Water-based acrylic materials are formulated for use in mainly dry, internal locations. Solvent-based acrylic materials are used to formulate intumescent coatings for use in internal or sheltered external locations. Solvent-based or solvent-free epoxy materials are used to formulate intumescents that can be used in any location. These resins have different weathering performance, and therefore, protection capabilities.

To test the durability of an intumescent coating, standard coating test procedures are used such as NORSOK M 501, “Surface preparation and protective coating,” Underwriters Laboratory, UL 1709, “Rapid Rise Fire Tests of Protection Materials for Structural Steel” and European Technical Approval Guidance, ETAG 18-2, “Reactive Coatings for Fire Protection of Steel Elements.”

In addition, the intumescent coating should not spall or crack in use, be resistant to atmospheric and chemical attack and be recoatable with itself — even after prolonged curing. There should also be excellent bonding between substrate, primers and the intumescent to combat the problems of under-film corrosion.

Specifying Fire Protection
Firstly, the item to be protected must be identified, whether it is structural steel, vessels or divisions such as fire-resistant bulkheads or decks on ships. The general
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rule is, the thicker the coating, the longer the protection—up to a limit. The thickness of the intumescent used will depend on the weight and type of the steel member being protected. As the weight of steel decreases, the thickness of the intumescent should increase. Lightweight steel sections will heat up faster than heavier sections and will therefore need more protection for a given time.

Rather than just figuring the weight of the steel, specific calculations must be made in order to determine the appropriate thickness of the coating, taking into consideration the shape or shapes of the steel and accounting for any cutouts or irregularities in the beams.

The critical steel temperature which must be protected against should be defined—for example, structural steel between 200 and 750°C, vessels between 200 and 350°C, or a 140°C temperature rise for divisions where the critical temperature requirement is much lower to protect personnel on the other side of the division or in a safety refuge.

Next the section factor must be considered, as well as the fire protection period of between 30 minutes and four hours. The section factor (Hp/A) is the ratio of the fire exposed perimeter to the cross-sectional area of the steel (Table 1, p. 56).

Most intumescent coating suppliers provide guidance in calculating the thickness of the coating required for a specific use and some have dedicated departments staffed with trained fire engineers who will do the calculations for you.

Consideration must also be given to the service environment the structure or vessel will be exposed to as well as any special requirements such as blast resistance, high or low substrate temperature or cryogenic spill protection.

Conclusion
In addition to offering fire protection for up to four hours, intumescent coatings offer speed of application, shop or field application, aesthetic appearance and ease of inspection and maintenance. Intumescent can protect a variety of steel surfaces from structural columns and cellular beams, to building components, vessels and complex shapes. They can be formulated to protect against cellullosic and hydrocarbon fires including jet fires and fires resulting from explosions.
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