Intumescent Coatings for advanced Passive Fire Protection

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Content

- Fire protection by intumescent coatings
- Specification principles
- Development and testing of intumescent products
- Global approvals
- Reliability and durability of intumescent coatings
- Approval of paint systems for fire protection
Introduction to fire & fire protection
Types of fires

There are 3 main types of fire

**Cellulosic fires**
- Occur when burning wood, textiles and paper etc.
- Civil construction

**Hydrocarbon fires**
- Occur when burning oil or gas
- O&G or petrochemical industry

**Jet fires**
- Occur when burning compressed oil and gas
- O&G or petrochemical industry
Types of fires

Temperature development of different fire types

- **Cellulosic fires**
  - ISO 834
  - \( T = 20 + 345 \times \log (8 \times t + 1) \)

- **Hydrocarbon fires**
  - UL1709/BS476
  - \( T = 20 + 1080 \times (1 - 0.325 \times e^{-0.167 \cdot t} - 0.675 \times e^{-2.5 \cdot t}) \)

- **Jet fires**
  - ISO 22899
  - Estimated temperature curve
Jet Fire Resistance (ISO22899-1)

- 1500x1500mm 10mm thick steel box with 250mm deep, 20mm thick flange (~500kg)
- Jet impinges on flange 375mm from base
  - 0,3kg/s ±0,05 kg propane
  - 260m/s velocity at impact area
- First thermocouple to 400°C = FAILURE!
  - Requires Epoxy intumescents
Active and passive fire protection

Fire protection of steel can be done with two methods:

Active fire protection
- Methods that require a certain amount of motion and response in order to react to put out the fire
- E.g. sprinkler systems, fire extinguisher systems

Passive fire protection
- Methods that contain, minimize the impact, or slow the spread of the fire
- Contrary to active fire protection, the passive type does not need a response before reacting to the fire
- E.g. intumescent coatings, boards, fire walls, foams
Cellulosic and Hydrocarbon intumescent

<table>
<thead>
<tr>
<th>Cellulosic Intumescent</th>
<th>Hydrocarbon &amp; Jet Fire Intumescent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Also called <strong>Thin film intumescent</strong></td>
<td>Also called <strong>Thick film intumescent</strong></td>
</tr>
<tr>
<td>Normally Acrylic based</td>
<td>Normally Epoxy based</td>
</tr>
<tr>
<td>Water or solvent based</td>
<td>Solvent free</td>
</tr>
<tr>
<td>1 component</td>
<td>2 component</td>
</tr>
<tr>
<td>Application by Airless Spray</td>
<td>Application by Plural Component Spray followed by trowelling</td>
</tr>
<tr>
<td>White</td>
<td>Grey/Blue/Beige</td>
</tr>
<tr>
<td>~0.2–5 mm dry film thickness</td>
<td>~2–40 mm dry film thickness</td>
</tr>
<tr>
<td>~40-60x expansion</td>
<td>~4-10x expansion</td>
</tr>
</tbody>
</table>
Normal airless and Plural Component spray equipment
Intumescent coatings for cellulosic fires
Basic concept of intumescent

- Intumescent is a substance which swells as a result of heat exposure, thus increasing in volume, and decreasing in density.

- Expansion is normally around 40-60 times the applied DFT

- Char of low thermal conductivity that reduces heat transfer to substrate

- Thermal insulation of substrate
Reactions during intumescence

- Softening of binder (Acrylic resin)
- Acid catalyst (Ammonium polyphosphate)

\[
\begin{align*}
(NH_4PO_3)_n & \xrightarrow{>300^\circ C} (HPO_3)_n - n NH_3 \\
(HPO_3)_n & \xrightarrow{>550^\circ C} \frac{n}{2} \text{H}_2\text{O} \xrightarrow{\frac{n}{4}} P_4O_{10}
\end{align*}
\]

- Carbon source (Pentaerithritol)

\[
(HPO_3)_n + C_x(H_2O)_m \rightarrow ["C"]_x + (HPO_3)_n \cdot m \text{H}_2\text{O}
\]

- Blowing agent (Melamine)

\[
\begin{align*}
\text{H}_2\text{N} & \text{N} \rightarrow \Delta \rightarrow \text{NH}_3 \\
& \text{O}_2 \rightarrow \text{N}_2 + \text{H}_2\text{O}
\end{align*}
\]
 Specification of fire protective coatings
Specification principles

Specifications of thickness of intumescent vary depending on the substrate and steel profile

- Factors influencing the specification
  - Type of section (open/ closed/cellular profile)
  - Massivity of the steel (Hp/A)
  - Exposure (i.e. 3 sided, 4 sided exposure)
  - Fire Rating FR (30/ 60/ 90/ 120 min)
  - Critical temperature (CT)
Hp/A concept

High Hp/A value
- Low mass of steel
- Fast heating
- Higher dry film thickness of intumescent

Low Hp/A value
- High mass of steel
- Slow heating
- Lower dry film thickness of intumescent
Hp/A concept

Hp/A factor

- Synonyms: A/V; Massivity; Section Factor
- Hp/A is a calculated numerical value \([m^{-1}]\)
- \(Hp\) = Heated Perimeter of the steel [m]
- \(A\) = Cross-sectional Area of the steel [m²]

\[
Hp/A = \frac{\text{Heated perimeter}}{\text{cross-sectional area}}
\]
Hp/A calculation

4 side-exposure

Hp = 1,140 m
A = 53,80 cm$^2$

Hp = 1,140 m
A = 53.80 $cm^2$

Hp/A = 212 m$^{-1}$

3 side-exposure

Hp = 0,940 m
A = 53,80 cm$^2$

Hp = 0,940 m
A = 53.80 $cm^2$

Hp/A = 175 m$^{-1}$
### Loading tables – 4 sided Columns

Table 11 Required thickness of HEMPCORE ONE 43600 or HEMPCORE ONE FD 43601 (mm) for a fire resistance period of 120 minutes

<table>
<thead>
<tr>
<th>Section factor (m(^{-1}))</th>
<th>Design temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>350</td>
</tr>
<tr>
<td>70</td>
<td>3.146</td>
</tr>
<tr>
<td>75</td>
<td>3.243</td>
</tr>
<tr>
<td>80</td>
<td>3.340</td>
</tr>
<tr>
<td>85</td>
<td>3.436</td>
</tr>
<tr>
<td>90</td>
<td>3.533</td>
</tr>
<tr>
<td>95</td>
<td>3.630</td>
</tr>
<tr>
<td>100</td>
<td>3.727</td>
</tr>
<tr>
<td>105</td>
<td>3.823</td>
</tr>
<tr>
<td>110</td>
<td>3.955</td>
</tr>
<tr>
<td>115</td>
<td>4.100</td>
</tr>
<tr>
<td>120</td>
<td>4.245</td>
</tr>
<tr>
<td>125</td>
<td>4.390</td>
</tr>
<tr>
<td>130</td>
<td>4.535</td>
</tr>
<tr>
<td>135</td>
<td>4.680</td>
</tr>
<tr>
<td>140</td>
<td>4.825</td>
</tr>
<tr>
<td>145</td>
<td>4.971</td>
</tr>
<tr>
<td>150</td>
<td>5.116</td>
</tr>
<tr>
<td>155</td>
<td>5.261</td>
</tr>
</tbody>
</table>

R90 (550°C): 1.360 mm
Hempel's R&D Fire Protection
Focussed investment to support Hempel’s growth plans

- Increasing legislation in fire protection
- Intumescent coatings are essential part of the protection system
- In the past, Hempel has had licensing agreements with other manufacturers
- The development of our own products is part of the growth strategy in Industrial protection
- State-of-the-art facilities
- Highly qualified experts

HEMPEL IR&D Centre in Polinya, Barcelona
New R&D Laboratory for Fire Protection
Standardized testing for fire resistance

![Graph showing furnace and steel member temperatures over time.](image-url)

- **Furnace temperature** depicted by a red line reaching 550°C.
- **Steel member temperature** shown as a green line.

**Temperatura (°C)**

- 0°C
- 200°C
- 400°C
- 600°C
- 800°C
- 1000°C

**Tiempo**

- 12:00:00 AM
- 12:28:48 AM
- 12:57:36 AM
- 1:26:24 AM
- 1:55:12 AM
- 2:24:00 AM
**Internal testing**

- Screening tests in small-scale furnaces
  - Plates 30x20 cm
  - Formulation adjustment

- Indicative tests in medium scale furnaces
  - Sections 1 meter
  - DFT range
  - Massivity range

**External testing**

- Official fire tests at third party institute
  - According to international standards
Global approvals for cellulosic products

- BS 476-21  Middle East, UK, APAC
- EN 13381-8  Europe
- UL 263  America, Middle East
- GB 14907  China
- GOST 53295  Rusia
- AS1530.4  Australia

- Other
  - Singapore BS8202
  - Korea – KS1227
Specification of Intumescent coating systems
Fire protection coating system

**Primer**
- Adhesion to substrate in cold state
- Anticorrosion protection
- Stickability of intumescent char formed during fire exposure

**Intumescent**
- Provides thermal insulation in fire exposure
- Contribution to anticorrosion by barrier effect

**Top-coat**
- Aesthetic function
- Sealer function to prevent early degradation and inactivation of intumescent layer
- Weathering resistance to end-use conditions
Typical intumescent coating systems

Medium/High corrosion category - Exterior areas up to C4 (ISO12944)
- Epoxy primer with Zinc phosphate 1 x 100µm HEMPADUR 15570
- Intumescent Coating 1 x acc spec. HEMPACORE ONE 43600
- Polyuretane topcoat 1 x 100µm HEMPATHANE 55610

Low/Medium corrosion category – Interior/exterior areas up to C3 (ISO12944)
- Epoxy primer with Zinc phosphate 1 x 80µm HEMPADUR 15570
- Intumescent Coating 1 x acc spec. HEMPACORE ONE 43600
- Acrylic Topcoat 1 x 50µm HEMPATEX ENAMEL 56360

Very low corrosion category - Interior areas up to C2 – indoor (ISO12944)
- Epoxy primer with Zinc phosphate 1 x 80µm HEMPADUR 15570
- Intumescent Coating 1 x acc spec. HEMPACORE ONE 43600
Extension of Assessment report to systems

- Classification of Resistance to Fire by Third party evaluation – FR 30, 60, 90, 120 minutes
  - EN, BS, UL standards
  - Fire testing of 1 paint system: primer/intumescent with or without topcoat

- BS8202
- ETAG18-2 – European Technical Approval Guideline – EOTA (since year 2008)
- Work in progress to new standard prEN16623
According to ETAG018 Part 2 – Technical Guideline
Issued by Notified Body – member of EOTA

Fitness for end-use:
- Resistance to fire (EN13381-8) – Loading tables
- Reaction to fire (EN13501-1) – Smoke generation and flame spread
- Primer compatibility - Substrates
- Durability of systems in weathering exposure conditions
- Slow heating exposure
- Identification (fingerprint) of primers and topcoats
Guidelines for compatibility testing of primers only in Europe - ETAG18-2

- Only 1 primer from each primer family is subjected to testing (separate for each intumescent product)

<table>
<thead>
<tr>
<th>Generic Primer Type</th>
<th>Maximum Approved Tested Thickness + (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>50</td>
</tr>
<tr>
<td>Short/medium oil alkyd</td>
<td>50</td>
</tr>
<tr>
<td>Two component epoxy</td>
<td>50</td>
</tr>
<tr>
<td>Zinc rich epoxy (containing about 80% by mass of metallic zinc powder)</td>
<td>50</td>
</tr>
<tr>
<td>Zinc silicate</td>
<td>50</td>
</tr>
</tbody>
</table>

- Substrates other than carbon steel must be tested with relevant primer
- Aim is to prove similar protection time than ref. primer used in initial type testing
- Fire tests at external lab on 2 panels per primer – 1000 microns DFT intumescent
- Multi-coat primer systems of more than one primer or more than one coat of the same primer shall be tested as one primer system
- A primer on top of a temporary blast primer (pre-construction) is not considered a multi-coat system
Compatibility testing of primers – ETAG18-2
Additional internal testing of primers

Good stickability steel-primer and primer-intumescent

Bad stickability: lack of adhesion steel-primer causing char detachment
Exposure conditions – topcoat approval

- Intumescent coatings are sensitive to humidity
- Topcoat act as sealer to prevent moisture penetration and ensure long-life
- Testing in different end-use conditions is necessary

- ETAG describes the following environmental conditions:

<table>
<thead>
<tr>
<th>Exposure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type X</td>
<td>Exterior</td>
</tr>
<tr>
<td>Type Y</td>
<td>Semi exposed</td>
</tr>
<tr>
<td>Type Z1</td>
<td>Interior high humidity</td>
</tr>
<tr>
<td>Type Z2</td>
<td>Interior</td>
</tr>
</tbody>
</table>
Increased reliability & durability

Exposure tests according to ETAG-018 Type X-conditions (outdoor conditions)

- Phase 1: **Spray QUV** (112 cycles in 28 days) of:
  - 5 hours of dry UV exposure at 50°C (± 3°C) with relative air humidity of 10% (± 5%)
  - 1 hour of water spray at 20°C (± 3°C)

- Phase 2: **Climatic chamber** (2 cycles as described in the below table where the coating is exposed to extreme temperature and humidity changes)

<table>
<thead>
<tr>
<th>Day</th>
<th>6 hours</th>
<th>6 hours</th>
<th>6 hours</th>
<th>6 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. + 2.</td>
<td>20°C ± 3°C 95% ± 5% rh</td>
<td>70°C ± 3°C 20% ± 5% rh</td>
<td>20°C ± 3°C 95% ± 5% rh</td>
<td>70°C ± 3°C 20% ± 5% rh</td>
</tr>
<tr>
<td>3. + 4.</td>
<td>20°C ± 3°C 95% ± 5% rh</td>
<td>30°C ± 3°C 40% ± 5% rh</td>
<td>40°C ± 3°C 95% ± 5% rh</td>
<td>30°C ± 3°C 40% ± 5% rh</td>
</tr>
<tr>
<td>5. + 6 +7.</td>
<td>-20°C ± 0°C</td>
<td>40°C ± 3°C 95% ± 5% rh</td>
<td>-20°C ± 3°C</td>
<td>40°C ± 3°C 95% ± 5% rh</td>
</tr>
</tbody>
</table>
Compatibility testing of topcoats – ETAG18-2

Weathered - X

Not weathered
Increased reliability & durability

- Results show superior durability under exterior conditions
Securing high quality
Quality control

- Factory Production Control - production only in approved and certified factories
- Quality control of raw materials and finished product
- Control of changes
- Process controls
- Initial audit
- Continuous surveillance
- Voluntary adoption of “Guidance to a quality control fire test regime for intumescent coatings” prepared by the Intumescent Coatings Technical Committee (ICTC) of CEPE
Quality assurance

Testing required for

- Changes in production equipment/processes
- Change of formulation
- Change in raw material supply

<table>
<thead>
<tr>
<th>Probability of effect on fire protection performance</th>
<th>Fire test level</th>
<th>Test to be performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certain</td>
<td>5</td>
<td>Loaded beam at maximum DFT according to EN 13381-8 at accredited laboratory</td>
</tr>
<tr>
<td>High</td>
<td>4</td>
<td>1 m specimens according to EN 13381-8 at accredited laboratory</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>1 m specimens according to EN 13381-8 internally</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
<td>Insulating efficiency test according to Laboratory Instruction RD-142</td>
</tr>
<tr>
<td>Very low</td>
<td>1</td>
<td>Char expansion test according to Laboratory Instruction RD-141</td>
</tr>
</tbody>
</table>
Wrap-up

- PFP of structural steel is a matter of safety

- Reliability and Durability of fire resistance coatings are essential – Only one chance to perform during lifetime of the building

- Third party certifications – Quality assurance

- Additional stringent internal test protocols
Thank you…