Optimization of Intumescent Fireproofing Via Structural Analysis

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Fire Engineer

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Learning Objectives / Overview

- **Structural Fire Protection**
  - Fire Resistance Ratings
  - Fire Testing Standards
  - Specification of Intumescent Fire Protection

- **What is Structural Fire Engineering**
  - Critical Core Temperature
  - Prescriptive vs Performance Based Fireproofing
  - Fireproofing Optimization

- **Benefits of Structural Fire Engineering**
  - Robust and Safe Designs
  - Quantified Structural Fire Performance
  - Cost Optimization
Presenter Bio – Alex D Tsiolas

- **Structural Fire Engineering Expertise**
  - BEng in Civil & Structural Engineering
  - MSc in Structural Dynamic
  - MSc in Fire and Blast Engineering

- **Expertise in:**
  - Intumescent Fire Protection
  - Fire Protection System Design
  - Fire Safety Codes
  - Fire Testing and Product Certification
  - Heat Transfer Modelling
  - Structural Fire Design
Structural Fire Protection
How is a fire defined in a building?

Fire Time / Temperature Relationships

- ISO 834 / BS 476
- UL 263 / ASTM E119-08a

Temperature (°C) vs. Time (mins)

- 740°C
- 840°C
- ~930°C
Design Codes and Standards

- There is a wide range of International fire safety codes that define all aspects of fire design in a building, including the structural fire resistance rating:
  - NFPA 101 – Americas, Canada and Middle East
  - International Building Code – Americas, Canada and Middle East
  - Approved Document B – England and Wales
  - British Standards: BS 9999 – UK
  - AS 4100 – Australia
How are Fire Resistance Ratings Set?

Fire resistance ratings are typically set by an architect or engineer using a simple look-up table.

Ratings are based on:

- **Occupancy use** (risk of fire)
- **Height of the structure** (for evacuation and access for fire-fighters)
- **Provision of a suppression system** (may act to control a fire)

Example: Office building, 100m high with a sprinkler system

Rating: **120 minutes** for load-bearing elements of structure

Above example based on BS 9999. Other standards or guidance documents may prescribe a different rating.
Fire Resistance Ratings

Defining a Fire Resistance Rating

- At 120 minutes for example, what is the acceptance criteria?
  - “Structural stability shall be maintained for a reasonable period of time…”

- Limiting steel temperatures
  - Associated closely to the Approval Standard
    - UL 263 / ASTM E-119: 538°C [1000°F] or 593°C [1100°F]
    - BS 476: 520°C, 550°C, 620°C (Guidance)

- Typical rating: **620°C at 120 minutes** (for a beam)

SCI 4th November 1997: “The existing temperatures of 550°C and 620°C are acceptable for most circumstances, but they are not always conservative.”
Fire Test Codes and Standards

- The design codes call for protection to elements of structures to be tested in accordance with one of a number of fire test standards, including:
  - UL 263 / ASTM E-119 – Americas, Canada & Middle East
  - BS 476: Part 21 – UK, Brazil, South East Asia, Belgium, New Zealand, Middle East
  - EN 13381 – Mainland Europe
  - AS 1530.4 – Australia
  - GB 14907 – China
  - GOST – Russia
A fireproofing material can extend structural stability in the event of a fire.

This extra time allows people to evacuate.

Unprotected Steel

Protected Steel

Critical steel temperature

Time (minutes)

Temperature (°C)

0 20 40 60 80 100 120

0 200 400 600 800 1000 1200 1400

10 minutes

90 minutes

Boards

Cementitious sprays

Insulation blankets

Intumescent coatings
Specification of Intumescent Fire Proofing
Selecting a Thickness of Paint

How do Suppliers Establish a Thickness of Intumescent?

Typically the following information is required: -

- Standard for approval:  
  e.g. BS 476: 20-22
- Fire resistance period:  
  e.g. 60 minutes
- Structural section:  
  e.g. I-beam
- Degree of exposure:  
  e.g. 3-sided with a concrete slab on top
- Limiting steel temperature:  
  e.g. 620°C
- Steel section:  
  e.g. UB 406x178x74

From these a supplier can determine a dry film thickness (DFT) of paint for a range of products that have 3rd party accreditation.

Further information can tailor a specific product for a project
  o Environmental exposure – degree of corrosion
  o Durability requirements
Section Factor

- The rate of temperature increase of a steel cross-section can be determined by the ratio of the **heated surface perimeter** to the **area** of the cross section.

\[ \text{Section Factor} = \frac{H_p}{A} \]

**Example**

UB 406x178x74: Exposed on 4 sides

Heated perimeter, \( H_p = 1.51 \text{m} \)

Cross-section area, \( A = 0.00945 \text{m}^2 \)

Section Factor, \( \frac{H_p}{A} = \frac{1.51}{0.00945} = 160 \text{m}^{-1} \)
Section Factor

- The section factor for a given structural steel component will change depending upon the heated perimeter value.

**UB 406x178x74**

- Exposed on 4 sides: \( Hp/A = 160 \text{m}^{-1} \)
- Exposed on 3 sides: \( Hp/A = 145 \text{m}^{-1} \)
- Exposed on 2 sides: \( Hp/A = 80 \text{m}^{-1} \)
Section Factor – \( H_p/A = A/V \)

How steel heats up

- **Slender Sections:** *High* Section Factor
  - Heat relatively **quickly** when unprotected

- **Stocky Sections:** *Low* Section Factor
  - Heat relatively **slowly** when unprotected

![Graph showing how steel heats up](image-url)

- **Furnace Temperature:**
  - **550°C**
  - **13 mins**
  - **32 mins**

- **Steel Temperature:**
  - High Section Factor (~165m-1)
  - Low Section Factor (~25m-1)
Selecting a Thickness of Paint

How do Suppliers Establish a Thickness of Intumescent?

Table 6: 1-Section Beams 620°C

<table>
<thead>
<tr>
<th>Section factor up to m²</th>
<th>Thickness mm</th>
<th>Section factor up to m²</th>
<th>Thickness mm</th>
<th>Section factor up to m²</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.275</td>
<td>60</td>
<td>0.280</td>
<td>90</td>
<td>0.552</td>
</tr>
<tr>
<td>35</td>
<td>0.275</td>
<td>65</td>
<td>0.282</td>
<td>95</td>
<td>0.602</td>
</tr>
<tr>
<td>40</td>
<td>0.282</td>
<td>70</td>
<td>0.286</td>
<td>100</td>
<td>0.677</td>
</tr>
<tr>
<td>45</td>
<td>0.286</td>
<td>75</td>
<td>0.293</td>
<td>105</td>
<td>0.747</td>
</tr>
<tr>
<td>50</td>
<td>0.286</td>
<td>80</td>
<td>0.293</td>
<td>110</td>
<td>0.827</td>
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<tr>
<td>55</td>
<td>0.297</td>
<td>85</td>
<td>0.297</td>
<td>115</td>
<td>0.917</td>
</tr>
<tr>
<td>60</td>
<td>0.302</td>
<td>90</td>
<td>0.302</td>
<td>120</td>
<td>1.016</td>
</tr>
<tr>
<td>65</td>
<td>0.308</td>
<td>95</td>
<td>0.308</td>
<td>125</td>
<td>1.116</td>
</tr>
<tr>
<td>70</td>
<td>0.308</td>
<td>100</td>
<td>0.312</td>
<td>130</td>
<td>1.225</td>
</tr>
<tr>
<td>75</td>
<td>0.312</td>
<td>105</td>
<td>0.312</td>
<td>135</td>
<td>1.339</td>
</tr>
<tr>
<td>80</td>
<td>0.312</td>
<td>110</td>
<td>0.312</td>
<td>140</td>
<td>1.457</td>
</tr>
<tr>
<td>85</td>
<td>0.320</td>
<td>115</td>
<td>0.320</td>
<td>145</td>
<td>1.584</td>
</tr>
<tr>
<td>90</td>
<td>0.320</td>
<td>120</td>
<td>0.320</td>
<td>150</td>
<td>1.734</td>
</tr>
</tbody>
</table>

Thickness is intumescent only. Three sided beams with a concrete slab.
Selecting a Thickness of Paint

Steel BOQ → MTO
Structural Fire Design

Safety Design in Buildings
17th June 2014

AkzoNobel
Alex D. Tsiolas
Fire Engineer
Selecting a Thickness of Paint

How do Suppliers Establish a Thickness of Intumescent?

Typically the following information is required:

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- Fire resistance period: e.g. 60 minutes
- Structural section: e.g. I-beam
- Degree of exposure: e.g. 3-sided with a concrete slab on top
- Limiting steel temperature: e.g. 620°C
- Steel section: e.g. UB 406x178x74

From these a supplier can determine a dry film thickness (DFT) of paint for a range of products that have 3rd party accreditation.

Further information can tailor a specific product for a project:
- Environmental exposure – degree of corrosion
- Durability requirements
The critical core temperature can be defined as the temperature that the steel will reach whilst still maintaining enough strength to carry an amount of load and thus prevent collapse.

This is not the temperature at which the structure will actually collapse.

Fireproofing manufacturers expect this to be provided in tenders, but it never is...
Prescriptive Design Approach

Prescriptive design does not consider the amount of actual load on a structural element, but assumes a fixed reduction factor approach sometimes known as fixed load ratio approach.

\[
\text{Load ratio} = \frac{\text{Load or moment at time of fire}}{\text{Member strength at } 20^\circ C}
\]

In the UK prescribed design assumes that an unprotected steel column will fail when its temperature reaches 550°C (1022°F) equating to a reduction factor of 0.6.

Similarly a temperature of 620°C will cause the failure of an unprotected steel beam supporting a concrete floor.
Prescriptive Fire Protection

Steel Utilization (e.g. 60%) >> Steel Utilization (e.g. 80%)

Limiting Steel Temperature == Limiting Steel Temperature

Fire Protection Thickness == Fire Protection Thickness
Structural Fire Engineering

Understanding Structural Engineering & Steel

Steel Strength vs Temperature

Assumes that the steel is loaded to a certain stress

Is this always the case?

Analysis at the Fire Limit State
Performance Based Fire Design

Steel Utilization (e.g. 60%) >> Steel Utilization (e.g. 80%)

Limiting Steel Temperature >> Limiting Steel Temperature

Fire Protection Thickness << Fire Protection Thickness
A limiting steel temperature for each member can be determined by a number of different calculations:

- Tensile or buckling resistance for tension or compression members
- Moment and shear resistance for beams
- Lateral torsional buckling resistance moment for beams

Beams with web openings have even more modes of failure to consider...
Multi-Temperature Assessment Data (MTA)

- UK and European fire testing methods (BS 476: 20-22 and EN 13381) make allowance for varying limiting steel temperatures
- US test methods work to a single 538°C [1000°F] or 593°C [1100°F] limiting temperature

<table>
<thead>
<tr>
<th>Table 1: I-Section Beams 400°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 minutes</td>
</tr>
<tr>
<td>Section factor up to m²</td>
</tr>
<tr>
<td>120</td>
</tr>
<tr>
<td>125</td>
</tr>
<tr>
<td>130</td>
</tr>
<tr>
<td>135</td>
</tr>
<tr>
<td>140</td>
</tr>
<tr>
<td>145</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>155</td>
</tr>
</tbody>
</table>

| Table 2: I-Section Beams 450°C |
| Table 3: I-Section Beams 500°C |
| Table 4: I-Section Beams 550°C |
| Table 5: I-Section Beams 600°C |
| Table 6: I-Section Beams 620°C |
| Table 7: I-Section Beams 650°C |
| Table 8: I-Section Beams 700°C |
### Structural Fire Engineering - Example

<table>
<thead>
<tr>
<th>Member Analysis</th>
<th>Section Factor Hp/A</th>
<th>Steel Temperature θ</th>
<th>Dry Film Thickness</th>
<th>No of Coats</th>
<th>Fire protection material saving</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> UKC 202x203x46 Industry standard temperature</td>
<td>200 /m</td>
<td>550°C</td>
<td>3.129mm</td>
<td>5</td>
<td>0%</td>
</tr>
<tr>
<td><strong>2</strong> UKC 202x203x46 Limiting temperature for a given applied loading</td>
<td>200 /m</td>
<td>576°C</td>
<td>2.816mm</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td><strong>3</strong> UKC 202x203x86 Limiting temperature as in 2 but with serial weight increased from 46 kg/m to 86 kg/m</td>
<td>110 /m</td>
<td>673°C</td>
<td>1.27 mm</td>
<td>2</td>
<td>59%</td>
</tr>
<tr>
<td><strong>4</strong> UKC 202x203x46 Limiting temperature as in 2 but steel yield strength increased from 235 N/mm² to 355 N/mm²</td>
<td>200 /m</td>
<td>639°C</td>
<td>2.213mm</td>
<td>3</td>
<td>29%</td>
</tr>
</tbody>
</table>
Optimisation

- Optimisation of steelwork and fire protection combined
- Large opportunities for designers to show up-front savings to their client – provided costs are accurately quantified

In some instances, steel can be cheaper than fireproofing materials
Structural Fire Engineering
DO’s & DON’Ts

DO
• Optimize fire proofing based on project requirements
• Question basis of temperature selections
• Question product limitations – Hp/A & Temperatures

DON’T
• Don’t accept material thicknesses without certifications
• Don’t accept increased limiting temperatures without a report
• Don’t accept anything that is not understood!!!
Benefits of Performance Based FP Design

Safe and Robust Designs in Buildings

• Demonstrate building integrity in a fire
• Identify potentially weak areas

Quantified Structural Performance

• Understand the limitations of steel at elevated temperatures
• Enable performance based design
• Add value in design
Benefits of Performance Based FP Design

Cost Optimization

- Enable performance based design of fire protection materials
  - Optimized construction material usage
  - Steel optimized on par with PFP to ensure max value
- Reduced number of coats resulting in faster preparation times
- Reduced scaffolding times
- Reduced erection times
- Reduced manhours on site
Summary

Intumescent Coatings
- Structural Fire Proofing
- Data Required for system design
- Process to establish material thicknesses/volumes

Structural Fire Design
- Critical core temperatures
- Steel behaviour at elevated temperatures
- Calculation of optimum steel temperatures

Benefits of Fire Design
- Promoting safe design in buildings
- Fire limit state should be treated as an important load case
- By addressing fire protection in early stages of design significant costs savings can be demonstrated
Thank you for your attention