The Performance and Protection of Bolted Connections in Fire
Agenda

• Introduction
• Overview of Fire Resistance & Key Structural Considerations
• Key Considerations for Connections
• Understanding of Connection Performance in Fire
• Options for Protection
• Summary

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The Performance and Protection of Bolted Connections in Fire

Introduction
Role of International Paint Ltd.

Solution Providers

International Paint Ltd. part of AkzoNobel are the world’s largest chemicals and coatings company, operating globally to provide solutions to our clients.

We provide a dedicated global structural fire resistance service for all projects including those in the commercial infrastructure, oil & gas and power markets.

We pride ourselves in being able to share our experience and capabilities of protection people and assets from the effects of fire.
The Performance and Protection of Bolted Connections in Fire

General Fire Resistance Considerations
Designer Responsibilities

• Came into effect 6th April 2015

• The person who selects a product is a designer and must take account of health and safety issues arising from the installation and use of those products.

• As a designer your decisions can affect the health and safety of workers and others who will construct, maintain, repair, clean, refurbish and eventually demolish the building or structure, as well as those who will use it as a completed workplace.

• Are you aware of your responsibilities with respect to fire resistance...?
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..?
  o “Structural stability shall be maintained for a reasonable period of time…”

• Limiting steel temperatures
  o Historically associated closely to the Approval or Fire Test Standard
    ▪ ULC / UL 263 / ASTM E-119: 538°C, 593°C
    ▪ BS 476: 520°C, 550°C, 620°C
    ▪ Europe: 500°C
    ▪ Offshore industry: 400°C

  • Typical rating: 550°C at 120 minutes (column exposed on 4 sides)

SCI 4th November 1997: “The existing temperatures are acceptable for most circumstances, but they are not always conservative.”
A fireproofing material can extend structural stability in the event of a fire.

- **Unprotected Steel**
  - Limiting steel temperature
  - 10 minutes

- **Protected Steel**
  - Limiting steel temperature
  - 90 minutes

**Quantified, Robust Design:**
- Connection Design Comparison

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1400</td>
<td>0</td>
</tr>
<tr>
<td>1200</td>
<td>10</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
</tr>
<tr>
<td>800</td>
<td>40</td>
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<tr>
<td>600</td>
<td>60</td>
</tr>
<tr>
<td>400</td>
<td>80</td>
</tr>
<tr>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>120</td>
</tr>
</tbody>
</table>

**Time (minutes)**

**Temperature (°C)**
Fire Protection Options

- Intumescent coatings
- Boards
- Cementitious sprays (SFRM)
- Insulation blankets
- Concrete filling
- Concrete encasement
- Bolt caps

*Images showing various fire protection options.*
Coating Thickness Determination

Consider a Fire Resistance Rating, e.g.: -

- Fire test standard: BS-476
- Exposure: 4-sided column
- Fire resistance period: 120 mins
- Section: 356x406x235 UC
- Limiting temperature (CCT): 550°C

The thickness for a connection is taken as the greatest used on the intersecting primary members

The connection is deemed to have more mass than the primary members and is therefore considered to be conservative

Is this always the case?
Bolted Connections for Steelwork

- Steel framed buildings are typically bolted together
- Bolted connections can be protected using any of the major methods
- Steel framed buildings can involve assembly and connections are made good on-site

Anecdotal evidence suggests that not all post-assembly protection is applied properly, especially in areas of poor regulatory inspection and rapid growth.
Types of Connection

Constructional steelwork unavoidably involves connections

Riveting
- Once popular now rare

Bolting
- Preferable for site construction

Welding
- Preferable for fabrication in shop

Bolts
- Standard / ordinary bolts
- High strength friction grip bolts
- Slip critical bolted connections
Types of Connection

Common types of connection

- Beam-to-beam
- Beam-to-column
- Column splices
- Bracing attachments
- Fin plates
- Web or flange cleats
- Flush end plate
- Flexible end plate
- Haunched connections
What Checks are Done for Fire?

‘Ambient’ design

Structural design loads assessed
Forces and moments defined
• Idealised e.g. pinned
Detailed design by specialist
Checked by the structural engineer

Bolt spacing
Direct shear
Moment connection
Bolt capacity checks
• Shear
• Tension
Structural Members in Fire
Disproportionate Collapse

This process can only occur if the connections are design and protected correctly.
Strength at Elevated Temperature

Eurocode 3 (1993-1-2)
- Failure at holes – no need for consideration
- Steel temperature is normally lower at connections due to the presence of additional material

The same strength reduction factor $k_{b,\theta}$ for bolts in shear and tension, regardless of bolt type

Under 60% permissible stress (100% design utilization)
Carbon steel failure temperature of 550°C
Bolt failure temperature of 478°C
The Performance and Protection of Bolted Connections in Fire

Background Research into Bolted Connections in Fire
Connection Research

Cardington tests in the UK (late 90’s)

- Whole frame behaviour
- Basis for validation of many computational methods and performance-based designs

- Localised beam buckling
- Partial connection failure – no overall collapse
Connection Research

Limited research

- Unprotected connections
- Few tests with composite concrete slabs
- Spring stiffness methods
- Detailed numerical modelling

Spyrou, 2002

Block, 2006

Hu et al., 2008

Anderson, 2006

Burgess, 2007
Connection Research

- Characterising performance of connections at temperature
- Database of test data available

EPSRC Project EP/C510984/1: Robustness of Joints in Fire, 2005-2008
Johnson L., Characterisation and performance of steels used in structural bolting assemblies in fire. The University of Sheffield, 2011.
The Performance and Protection of Bolted Connections in Fire

Protection Options
Methods of Fire Protection

Cementitious application
Methods of Fire Protection

Intumescent coatings
Methods of Fire Protection

Coating cracking on bolts

Inconsistent thickness of coating

Uncoated threads

Poor architectural appearance
Methods of Fire Protection

Ease of access to ensure application?

Poor quality bolt protection
Industry Positions

**BS 5950-8 Structural use of steelwork in building — Part 8: Code of practice for fire resistant design** (now withdrawn)

- Thickness of fire protection on various parts of the connection should be the same as that on the connecting members (provided its load ratio is equal to or less than the load ratio on the connecting members).

- If load ratio of connection is higher than connecting members then base thickness of connecting members on load ratio of the connection.

- It is possible to reduce the protection to the bolts where test evidence is available.
Industry Positions

Association of Specialist Fire Protection (ASFP)

Technical Guidance Document 11
Code of practice for the specification & on-site installation of intumescent coatings for fire protection of structural steelwork

<table>
<thead>
<tr>
<th>Type</th>
<th>Preparation Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolts</td>
<td>Bolts/connection may require cleaning and a special adhesion primer</td>
</tr>
<tr>
<td>Galvanised bolts</td>
<td>Flash blasting or degreasing followed by a use of a mordant solution (T-wash) to etch surface</td>
</tr>
<tr>
<td>Sheradised bolts</td>
<td>Degreasing</td>
</tr>
<tr>
<td>Black bolts</td>
<td>Degreasing</td>
</tr>
</tbody>
</table>

In all instances, other preparation techniques may be employed depending on the intumescent manufacturer’s experience and the severity of the subsequent service conditions.
Connection preparation by masking-off

- Applicator will typically need to make provision for protection on bolts and connection after erection.
- Contact faces between connected members are typically masked off. Experience shows that excessive build up of coating on contact faces can cause problems with bolt tightening.

<table>
<thead>
<tr>
<th>Type</th>
<th>Preparation Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary bolts</td>
<td>Masking off on contact faces when DFT is greater than 1mm although some applicators use masking at lower thicknesses.</td>
</tr>
<tr>
<td>HSFG bolts</td>
<td>No intumescent coating should be applied to contact faces. Care should be taken on outside faces on connection as excessive DFT under the head of the bolt or nut may affect preload in the HSFG bolt.</td>
</tr>
</tbody>
</table>
Alternative Masking Options

We have developed re-usable masking bungs available in both metric and imperial bolt sizes to reduce the cost of off site masking.

These bungs have been designed to suit the bolt hole dimensions and the outer bolt cap dimensions.

These are especially useful when building modular sections off site that need to be connected on site without the need for site painting.

The bungs are placed in the end plate or connection outer face and the column or beam inner face prior to painting. The facing surfaces are left unpainted. Once the fire protection is dry they can be removed leaving a clean surface for the bolts to be placed and tightened without damage to paint, bolt caps are then installed over to close the gap and fully protect the connection. Hence reducing the need for site touch up or site painting which ultimately reduces cost and programme.
Interchar Bolt Caps

Alternative fire protection option

<table>
<thead>
<tr>
<th>Built Environment</th>
<th>Oil &amp; Gas Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-476 (2 hrs)</td>
<td>UL 1709 (2 hrs pool fire)</td>
</tr>
<tr>
<td>ASTM E-119 / UL 263 (3 hrs)</td>
<td>ISO 22899 (2 hr jet fire)</td>
</tr>
</tbody>
</table>

- Complements intumescent coatings
- Internal and external application
- Quick and easy to apply
Joint Tightening

- Steel structures are erected in an agreed sequence using temp and permanent bracing.
- This sequence is usually based on deliverable loads of steel fabricated on a ‘JIT’ basis.
- During the erection process all connections are fully bolted but not fully tightened.
- The erection sequence has ‘handover points’ to suit following trades.
- Once a ‘handover section’ is complete the erectors ‘plumb, line & level’ the steel frame.
- This process requires some of the connections to be loosened off and to allow the frame to be moved and subsequently tightened.
- Once the building is ‘plumb, lined & level’ all connections are fully tightened including any HSFG/TCB bolts.
- We would recommend that bolt caps are installed during this process.
Maintenance

- Regular building maintenance is always required and is outlined in the ‘O & Ms manual’.
- This maintenance process also includes for the inspection of paint finishes including connections.
- The use of bolt caps assists in this process as they are visually easier to check and ensure they are in place.
- It is sometimes not practical to access every connection and therefore not always easy to maintain.
- The clipping system on Bolt Caps ensures that the only way of removal is by physically prising them off.
- Thus long term integrity of the connection is maintained.
Application

The installation of bolt caps is simple and can be achieved on site in seconds with minimal site training required.

Above is a brief video of the bolt cap material undergoing a jet fire test.
Bolt Caps can be cast in a range of flat colours but are also able to be overcoated without the need for preparation.

In some circumstances the caps have been used on site and then the connections have been fully painted.

If they are being used on previously treated bolts there is no need to remove the existing coating simply apply the cap over the pre treated bolt, simple and cost effective.

The bolt cap also allows for ease of future maintenance of the bolts, simply remove the cap via our unique screw clip inspect the bolt and then replace the cap.
## Cap Size Availability

### Metric Bolt Cap overall dimensions

<table>
<thead>
<tr>
<th>BOLT SIZE</th>
<th>DIMENSION A (mm)</th>
<th>DIMENSION B (mm)</th>
<th>WALL THICKNESS (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M16</td>
<td>47.0</td>
<td>43.0</td>
<td>5</td>
</tr>
<tr>
<td>M20</td>
<td>53.0</td>
<td>45.0</td>
<td>5</td>
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<tr>
<td>M24</td>
<td>59.0</td>
<td>53.0</td>
<td>5</td>
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<tr>
<td>M30</td>
<td>70.0</td>
<td>63.0</td>
<td>5</td>
</tr>
</tbody>
</table>
# Cap Size Availability

## Imperial Bolt Cap overall dimensions

<table>
<thead>
<tr>
<th>BOLT SIZE</th>
<th>DIMENSION A (mm)</th>
<th>DIMENSION B (mm)</th>
<th>WALL THICKNESS (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4&quot;</td>
<td>50.0</td>
<td>47.0</td>
<td>5</td>
</tr>
<tr>
<td>7/8&quot;</td>
<td>56.0</td>
<td>53.0</td>
<td>5</td>
</tr>
<tr>
<td>1&quot;</td>
<td>63.0</td>
<td>58.0</td>
<td>5</td>
</tr>
</tbody>
</table>

Custom sizes may be made to order
Bolted connections to structural steelwork shall receive protective Interchar tap-on bolt caps with mechanical clip fixings, which eliminates the need to clean and prepare bolts.

Alternatively, subject to the provision of suitable test data and work application sheets, bolts can be fire protected with an intumescent coating applied to bolt surfaces which have been etched and primed in accordance with the National Physical Laboratory good practice publication “Surface Preparation for Coating”. Intumescent coatings must be applied and subsequently checked for film thickness in accordance with the ASFP TGD11 Code of Practice for onsite application (as amended 14th September 2014), provided test data is supplied to demonstrate that adherence to the work sheets will provide the same coating able to provide the same standard of performance as tested by the intumescent coating manufacturer.
# Chartek Bolt Caps Track Record

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Location</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunoco Logistics Marcus Hook</td>
<td>USA</td>
<td>2 hr UL1709</td>
</tr>
<tr>
<td>Dominion Cove Point LNG</td>
<td>USA</td>
<td>2 hr UL1709</td>
</tr>
<tr>
<td>St. Laurent Sports Complex</td>
<td>Canada</td>
<td>2 hr UL263</td>
</tr>
<tr>
<td>Valero Refinery</td>
<td>USA</td>
<td>2 hr UL1709</td>
</tr>
<tr>
<td>El Dorado Refinery</td>
<td>USA</td>
<td>1.5 hr UL1709</td>
</tr>
<tr>
<td>Mont Belvieu 3&amp;4 (Oneok)</td>
<td>USA</td>
<td>2 hr UL1709</td>
</tr>
<tr>
<td>Cameron Bridge Distillery</td>
<td>UK</td>
<td>2 hr BS476</td>
</tr>
<tr>
<td>Dublin Airport</td>
<td>UK</td>
<td>1 hr BS476</td>
</tr>
<tr>
<td>Victoria Embankment</td>
<td>UK</td>
<td>75 Min BS476</td>
</tr>
</tbody>
</table>
Oil and Gas Projects.

The bolt cap is also now being specified on many future projects as a cost effective solution to the fire protection of connections in the field particularly when the environment is very cold or humid and the application of traditional protection is difficult.

Dublin Airport Main Car Park

[Image of the bolt cap in a project context]
Protection of Connections

• Designers have responsibilities at the fire limit state
• The fire protection of connections can be very important
• Ensuring an adequate level of protection is key
• Interchar Bolt Caps provide an innovative and robust protection option
• Benefits: -
  – Speed of application
  – Cost savings
  – Fire resistance performance
Delivering Leading Performance