Temperature Distribution in Intumescent Coating Protected Steel Connections in Fire

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4 typical joint types adopted

(a) Flush endplate joint
(b) Flexible endplate joint
(c) Fin plate joint
(d) Web cleat joint

Column:
UC254x254x89
Length 1000mm.

Beam:
UB305x165x40
Length 605mm, 485mm.

Slab:
1000x1000mm
Overall depth 130mm.
Outline of fire protection options

- Protecting a segment of beam of 300mm or 400mm from the connected end.
- Leaving the bolts unprotected in a protected joint assembly.
- Protecting column only.
Typical fire protections applied

(a) reduced beam protection
(b) protected bolts
(c) unprotected bolts
(d) protected column only
Specimen set-up

(a) View from inside the furnace
(b) View from outside the furnace
Main research objectives

- Effect of protecting a small segment of the beam near the joint on temperature developments in joint components
- Effect of not protecting bolts on temperature developments in joint components
- Effect of protecting column only on temperatures in joint components and column itself
- Develop a simple calculation method to predict temperature distribution in connections protected using intumescent coating
Effect of partial beam protection on to connection components (1)

Protecting a segment of the connected beam for about 400mm from the connected end behaved as full beam protection to connection components.
Effect of partial beam protection on to connection components (2)

Protecting a segment of the connected beam for about 400mm from the connected end behaved as full beam protection to bolts.
Effect of not protecting bolts on the connection components in a protected joint (1)

Whether or not protecting the bolts had minor influence on temperature developments in the protected connection components.
Effect of not protecting bolts on to connection components in a protected joint (2)

Higher temperatures in unprotected bolts but still much lower than bolt temperature in an unprotected joint

Bolt heads were not covered by char

Test USP4, unprotected specimen
Test SP2, protection scheme: FP-B
Test SP1, protection scheme: FP+B

After fire test
Temperature in unprotected bolt got closer to protected bolt temperature

Bolt heads were covered by char

Test USP1, unprotected specimen

Test SP8, protection scheme: FP_B

Test SP7, protection scheme: FP+B
Effect of protecting column only (1)

Protecting column only appeared to give similar temperatures in connection components on beam web side as unprotected.
Effect of protecting column only (2)

Protecting column only slightly reduced temperatures in connection components connected to column flange.

Test SP3, protecting column only
Test USP4, unprotected specimen
Test SP1, total protection

Graph showing temperature over time for different tests.
Effect of protecting column only (3)

Protecting column only substantially reduced temperatures in fin plate weld on column flange.

Weld in Test SP6, protecting column only
Weld in Test USP3, unprotected specimen
Weld in Test SP4, total protection
Column section remote from joint in Test SP6, protecting column only.

Temperature (°C) vs. Time (minutes) graph:
- Weld in Test SP6, protecting column only
- Weld in Test USP3, unprotected specimen
- Weld in Test SP4, total protection
- Column section remote from joint in Test SP6, protecting column only.
Conclusions by fire tests

- Protecting a segment of the connected beam for about 400mm from the joint appeared to be sufficient to achieve full protection for the joint.
- Whether or not protecting bolts had little influence on temperatures in other connection components in a protected joint.
- In a protected joint with unprotected bolts, the unprotected bolt temperatures were higher than those with full bolt protection, but still much lower than bolt temperatures in a completely unprotected joint.
- Protecting the column only in a joint appeared not reduce to the unprotected connection component temperatures, however the protection did reduce temperatures in components immediately contacting column flanges.
**Temperature assessment methods provided in EN 1993-1-2:2005 for steel sections**

**Temperatures in unprotected steel sections**

\[
\Delta \theta_{a,t} = K_{sh} \frac{A_m}{V} \frac{A_p}{C_a \rho_a} \dot{h}_{net} \Delta t
\]

**Temperatures in fully protected steel sections using coating**

\[
\Delta \theta_{a,t} = \left\[ \frac{\lambda_{p,t}}{c_a \rho_a} \frac{d_p}{V} \times \frac{A_p}{1+\phi/3} \times (\theta_t - \theta_{a,t}) \Delta t \right\] - \left[ (e^{\phi/10} - 1)\Delta \theta_t \right]
\]

\[
A_m / V \quad \text{calculation method provided in EN 1993–1–2:2005}
\]

\[
\lambda_{p,t}(t) = \left[ \frac{d_p}{A_p} \times \frac{V}{c_a \rho_a \times (1+\phi/3) \times \frac{1}{(\theta_t - \theta_{a,t})\Delta t}} \right] \times \left[ \Delta \theta_{a,t} + (e^{\phi/10} - 1)\Delta \theta_t \right]
\]

*(calculation method provided in ENV13381–4:2002)*
Temperatures in standard steel sections

The simple calculation method provided in EN 1993-1-2:2005 may be used to assess temperatures in standard steel sections.
Approximate 2-D calculation methods for
Section factors and exposure factors for typical connections

\[ F_s = \frac{2 \times (W_{cf} + t_{cf} + t_e)}{W_{cf} \times t_{cf} + W_e \times t_e} \]

\[ F_e = 4 \times d_b \left/ \left(2 \times W_{cf} + 2 \times t_{cf} + 2 \times t_e\right) \right. \]

\[ F_s = \frac{2 \times (L_{f1} + t_{cf} + W_{cf})}{(L_{f1} - t_e) \times (2 \times t_c + t_w) + 2 \times L_{f2} \times t_e + W_f \times t_f} \]

\[ F_e = 8 \times d_b \left/ (2 \times L_{f1} + 2 \times t_{cf} + 2 \times W_{cf}) \right. \]

\[ F_s = \frac{2 \times (L_f + t_f + t_w)}{L_f \times (t_f + t_w)} \]
3-D calculation methods for
Section factors and exposure factors for fin connections

\[ F_s = \frac{(2L_f + t_f + t_w)H_f + A_{bs}n_b}{(t_f + t_w)L_fH_f + V_{bo}n_b} \]

\[ F_e = A_{be}n_b / [(2L_f + t_f + t_w)H_f + A_{bs}n_b] \]

\( n_b \): Bolt quantity in the analyzed joint.

\( V_{bs} \): Side surface area of a bolt excluding the part inside the connected members.

\[ V_{bs} = 2 \times \pi d_b h_b \]

\( V_{bo} \): Volume of a bolt and nut excluding the part inside the connected members.

\[ V_{bo} = 2 \times \pi \frac{(d_b^2}{2} h_b \]

\( V_{be} \): Two end surface area of a bolt.

\[ V_{be} = 2 \times \pi \frac{(d_b^2}{2} \]
Temperatures in fully protected joint components

(a) Temperatures in web cleat (SP1)

(b) Temperatures in fin plate (SP4)

The simple calculation method may be used to assess temperatures in fully protected joint components using appropriate section factors.
Temperatures in partially protected joint components
(leaving bolts not protected in a protected joint)

1. Temperatures in protected components may be calculated by assuming the joint is fully protected.

2. Temperatures in unprotected bolts may be approximately calculated by the following method:

\[ T_{pp} = T_{fp} + (T_{up} - T_{fp}) \cdot F_e \]

\( T_{up} \) and \( T_{fp} \) Calculated using the simple calculation method

\( F_e \) Exposure factor calculated using the approximate calculation method as described previously
The simple calculation method may be used to predict Temperatures in unprotected bolts in a protected joint with appropriate section factors and exposure factors.

(a) Temperatures in unprotected bolts in a protected fin plate (SP5)

(b) Temperatures in unprotected bolts in a protected endplate (SP10)
Conclusions by numerical analyses

The simple calculation methods provided in EN 1993-1-2: 2005(E) can be used to predict temperature developments in unprotected and protected joint components. However, appropriate exposure factors should be used in prediction of temperatures in unprotected bolts in a protected joint.
Comments and further studies

- Limitation of specimen quantity, joint types and joint dimension.
- Will the conclusions and calculation methods hold for joints with other dimensions and types? Validation and parameter studies are being done by in the University of Manchester.
Thank you for your attendance