Fire Resistance of Protection Steel Rods Subject to Tensile Loading

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Fire Resistance of Protected Steel Rods Subject to Tensile Loading

Introduction
Introduction

Aim

• To assess the performance of a passive fire protection system (intumescent coating) on a solid steel rod subject to a tensile load when exposed to fire

Is there a need to test a rod in tension for fire protection product validation?

Additionally, assess performance in relation to:

• Section factor
• Curvature
• Rod length
• Product thickness
Introduction

Witnessing

• Test carried out at UKAS accredited fire resistance testing laboratories of International Paint Ltd.

• 19th August 2014

• Witnessed by: -
  • Allan Jowsey – Fire Engineering Manager, International Paint Ltd.
  • Brian Kirby – ISO TC92 SC2 WG2 Convenor
  • Phil Crewe – UL UK Principle Engineer
  • Dustin Häßler – Research student, BAM Federal Institute for Materials Research and Testing
  • Ian Bradley – UK delegate to ISO TC92 SC2
  • Erik Hudson – Pyro Fire
Key Considerations

Curvature and Section Factor

\[ \kappa = \frac{1}{R} \]

Schematic of a solid rod (left) and CHS section (right) with similar sections factors

Curvature of rods and CHS sections with respect to section diameter
Introduction

Curvature and Section Factor

Section factor of rods and CHS sections with respect to section diameter

Section Diameter (mm)

Rods
CHS Sections
Introduction

Curvature and Section Factor

Curvature of rods and CHS sections with respect to section factor

Curvature, \( k (1/r) [m^{-1}] \)

Section Factor (m^{-1})

- Rods
- CHS Sections
Test Philosophy and Setup

Philosophy

- Loaded section and unloaded section
- 6000mm long rod (5560mm between supports, 4403mm heated)
- Bespoke structural frame supported on walls of floor furnace
- Tensile force applied using a hydraulic jack

- Rods identical, except their loading
- DFT selected to achieve no higher than 600°C steel temperature at 60 minutes

- Strain developed in coating on loaded rod is key for assessment of coating performance

- Test to EN 1363-1
- Test terminated when the rod snapped
Test Philosophy and Setup

Philosophy and test specimens

International Paint Ltd.'s large floor furnace prior to addition of the structural tension frame
Test Philosophy and Setup

Philosophy and test specimens

Structural tension frame showing columns, intermediate compression struts, concrete slab and steel rod
Test Philosophy and Setup

Philosophy and test specimens

Addition of the structural tension frame onto the walls of the large floor furnace. The height of the furnace was increased accordingly.
Test Philosophy and Setup

Philosophy and test specimens

Selection of rods and CHS sections prior to coating (left) and after thermocoupling and coatings (right)
Test Philosophy and Setup

Philosophy and test specimens

Test setup prior to furnace burn showing the two rods and surrounding protected structural tension frame.
The upper rod is under load, while the lower rod is simply supported.
Test Philosophy and Setup

Test Specimens

- Horizontal orientation
- Steel blasted and primed in accordance with typical procedures
- Coating thicknesses informed from previous unloaded testing on slender rods

**Table 1: Overview of test specimens**

<table>
<thead>
<tr>
<th>Ref</th>
<th>Section</th>
<th>Diameter (mm)</th>
<th>Curvature (m⁻¹)</th>
<th>$A_m/V$ (m⁻¹)</th>
<th>Length (m)</th>
<th>DFT (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR1</td>
<td>M36</td>
<td>34</td>
<td>59</td>
<td>118</td>
<td>6</td>
<td>4.500</td>
</tr>
<tr>
<td>LR2</td>
<td>M36</td>
<td>34</td>
<td>59</td>
<td>118</td>
<td>6</td>
<td>4.500</td>
</tr>
<tr>
<td>LR4</td>
<td>M36</td>
<td>34</td>
<td>59</td>
<td>118</td>
<td>2</td>
<td>2.000</td>
</tr>
<tr>
<td>SR3</td>
<td>M36</td>
<td>34</td>
<td>59</td>
<td>118</td>
<td>1</td>
<td>2.000</td>
</tr>
<tr>
<td>SR4</td>
<td>M36</td>
<td>34</td>
<td>59</td>
<td>118</td>
<td>1</td>
<td>4.500</td>
</tr>
<tr>
<td>SR7</td>
<td>M20</td>
<td>20</td>
<td>100</td>
<td>200</td>
<td>1</td>
<td>4.500</td>
</tr>
<tr>
<td>CHS1</td>
<td>CHS 33.7x3.2</td>
<td>33.7</td>
<td>59</td>
<td>345</td>
<td>1</td>
<td>4.500</td>
</tr>
<tr>
<td>CHS2</td>
<td>CHS 139.7x5</td>
<td>139.7</td>
<td>14</td>
<td>205</td>
<td>1</td>
<td>4.500</td>
</tr>
<tr>
<td>CHS3</td>
<td>CHS 139.7x10</td>
<td>139.7</td>
<td>14</td>
<td>110</td>
<td>1</td>
<td>4.500</td>
</tr>
</tbody>
</table>

LR denotes ‘long rod’
SR denotes ‘short rod’
CHS denotes ‘circular hollow section’
## Test Philosophy and Setup

### Test Specimens

<table>
<thead>
<tr>
<th>No.</th>
<th>Purpose</th>
<th>Test specimen references for comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strain</td>
<td>LR1 (loaded rod) vs LR2 (unloaded rod)</td>
</tr>
<tr>
<td></td>
<td>To assess the influence of longitudinal strain, i.e. a rod loaded in tension in comparison to a load not loaded in tension.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rod length</td>
<td>LR4 (2m rod) vs SR3 (1m rod) and LR2 (6m rod) vs SR4 (1m rod)</td>
</tr>
<tr>
<td></td>
<td>To assess the influence on length on the intumescent coating</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Curvature</td>
<td>SR4 ($\kappa = 59m^{-1}$) vs CHS3 ($\kappa = 14m^{-1}$) and SR7 ($\kappa = 100m^{-1}$) vs CHS2 ($\kappa = 14m^{-1}$)</td>
</tr>
<tr>
<td></td>
<td>To assess the influence of curvature on rod and CHS specimens with the same or similar section factor</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Section factor</td>
<td>SR4 ($A_m/V = 118m^{-1}$) vs CHS1 ($A_m/V = 345m^{-1}$) and CHS2 ($A_m/V = 205m^{-1}$) vs CHS3 ($A_m/V = 110m^{-1}$)</td>
</tr>
<tr>
<td></td>
<td>To assess the influence of section factor on rod and CHS sections with the same curvature</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Product thickness</td>
<td>SR3 (DFT = 2.000 mm) vs SR4 (DFT = 4.500 mm)</td>
</tr>
<tr>
<td></td>
<td>To assess the influence of product thickness on identical rod specimens</td>
<td></td>
</tr>
</tbody>
</table>
Test Philosophy and Setup

Instrumentation: Thermocouples

Schematic of the thermocouple measuring stations for long rods, short rods and CHS sections.

Schematic of the positions of thermocouples each measuring station for the long rods, short rods and CHS sections.

The above thermocouple requirements for short rods and long rods are taken directly from the draft ISO 834-14 standard with minor amendments.
Test Philosophy and Setup

Instrumentation: Thermocouples on compression struts
Test Philosophy and Setup

Instrumentation: Measurement of elongation

- Total extension recorded before and during test
- Scribes at 200mm intervals marked along rod length

Positions of scribes at 200mm intervals along the length of the loaded rod
Test Philosophy and Setup

Instrumentation: Loading apparatus

Model number: **RRH-1508**
Cylinder capacity: 145 ton / 1429 kN
Stroke: 203 mm
Centre hole diameter: 79.2 mm

Enerpac

Hollow plunge cylinder loading apparatus positioned on the tension loading frame

Fixed end of the loaded rod (top) and unloaded rod (bottom)
Test Philosophy and Setup

Loading

- Design test based on characteristic values and principles of EN 1993-1-2
- Intention: test coating at high strain and temperature
- 60% of ultimate capacity at 600°C
- High (realistic) temperature causes greater thermal expansion of steel and coating
- Load applies a small amount strain
- Thermal expansion produces largest degree of strain

Cross-section of bar showing effective area resulting from a 3mm drill-hole to place the thermocouple
Images

Unloaded rod during the test showing expansion of intumescent and thermocouple cables (courtesy D. Häßler)
Images

Detail of the char and necking of the steel rod at the snap position
Images

Detail of intumescent char along the length of the loaded rod after the test
Images

Cross-section view of the char formation on a solid rod
Results

Temperatures Recorded at a Single Measuring Station

 Recorded temperatures at individual thermocouples (TC) at Station C on LR1
Results

Temperature Distribution Along the Loaded Rod

Average station temperatures along the loaded rod at 5 minutes intervals throughout the test.
Maximum recorded temperatures at any station along the loaded and unloaded rods. Averaged temperatures for each rod are shown for comparison.
Results

Total elongation of the loaded rod

Elongation due to load = 12 mm
Elongation at rupture = 53 mm
## Results

### Localised elongation of the loaded rod

| Rod length (mm) | 0 | 200 | 400 | 600 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 | 2200 | 2400 | 2600 | 2800 | 3000 | 3200 | 3400 | 3600 | 3800 | 4000 | 4200 | 4400 | 4600 | 4800 | 5000 | 5200 |
|-----------------|---|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|

### Distance between scribes prior to test (mm)

|                | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 |

Localised elongation of the loaded rod along its length before and after the test
Assessment of strain:

LOCALISED

Consider a 200mm length

Maximum temperature of 673°C

Total theoretical expansion due to load and temperature = 2.82mm

Equates to a localised strain of 1.409%
The following conclusions can be drawn:

1. The imposition of a tensile load on a steel rod has negligible influence on the performance of the intumescent coating in comparison to an unloaded rod. Despite localised deformation resulting in high strains the intumescent coating did not lose its cohesion. A tension test is therefore not required of industry. It should be noted that any passive fire protection product proposed for rods should demonstrate alternative testing to ensure adhesion/stickability and insulation efficiency at representative strains commensurate with those expected in design.

2. The measured strain is less than that measured on the lower flanges of loaded beams at their limit of deflection (typically 3%). I.e., for assessing adhesion of a passive fire protection material, a loaded beam test provides the most onerous scenario.
Conclusions

The following conclusions can be drawn:

3. The specimen failed locally with an overall strain of around 15.4%. This indicates the types of steel used in any industry test should be limited to those that demonstrate a reasonable level of ductility at high temperature, i.e. hot rolled structural steel.

4. The strain due to the applied load is very small and the range of strain that the coating is subjected to during the test may give an indication that a test on post-tensioned coating is not required.

5. It was possible to link the strain at the onset of runaway failure to a rod temperature. The rod failed at the predicted temperature, but this was a localised temperature. This highlights that the total strain was low at failure because the temperature along the rod was non-uniform.
Conclusions

The following conclusions can be drawn:

6. The localised strain observed during the test demonstrates that non-uniform heating of the rod can lead to failure at strains not commensurate with the average temperature of the rod. The average of all thermocouples on the rod should not be used for any assessment purposes.

7. A tension test is not required.