ON BOLTED CONNECTION WITH INTUMESCENT COATINGS

FRANTIŠEK WALD¹, MICHAL STREJČEK², ALENA TICHÁ³

ABSTRACT

The paper is focussed to the temperature development in the bolted connections, which are fire protected by intumescent coating. Three tests were arranged to study the influence of coatings on bolts. On unprotected bolts in the fire protected connections was measured temperature higher till 17 % compare to protected bolts. The analytical model of prediction of the temperature of connection in EN 1993-1-2 is applied to the prediction of bolted connection in case of its installation without coating.

1. INTRODUCTION

The fire will affect the structural connections by reduction of the material properties, redistribution of internal forces and non-homogenous heating of connection components. The temperature of the steel in the region of the connection is lower than the rest of the structural member, due to the increased of thicknesses steel and the shielding effect of the connected member. By the concentration of mass in a joint, compare to connected element, is the connection heated later compare to beam and on reverse during cooling is the temperature in connection higher compare to connected beam, see [1].

The fire resistance of a bolted or a welded joint may be assumed, see [6], to be sufficient provided that the thermal resistance \((d_f/\lambda_f)_c\) of the joint's fire protection should be equal or greater than the minimum value of thermal resistance \((d_f/\lambda_f)_m\) of fire protection applied to any of the jointed members, where \(d_f\) is the thickness of the fire protection material, where for unprotected members is expected \(d_f = 0\). \(\lambda_f\) is the effective thermal conductivity of the fire protection material. The utilization of the joint should be equal or less than the maximum value of utilization of any of the connected members and the resistance of the joint at ambient temperature should satisfy the recommendations given in EN 1993-1-8 [7]. For structural steel is now the temperature of connection predicted by two methods, the background see in [2], [3], [4] and [5]. The connection temperature may be calculated using

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the section factor $A_m/V$ (or $A_p/V$) of components creating the joint, where $A_m$ is the surface area of connection exposed to heat, $A_p$ internal area of fire protection and $V$ the volume of joint per unit length. For beam to column connection and beam to beam connection, which is supporting the concrete slab may be the temperature predicted from the temperature of the mid span of the beam. By this model is expected that the temperature of the connection component depends on the vertical distance from the upper part of the connected beam. The influence of mass is express indirectly in the prediction of the temperature of the lower flange at midspan.

The intumescent coatings are commonly used to provide fire protection to construction steelwork, and in some countries reached of a 40 % of multi-storey marked, see [8]. The principles by the coatings work are well understood, because the first patent on intumescents was granted as early as 1938. About one third of coatings are provided on-site. Off-site application has major features in cost savings, improved quality by better quality control, reduction of in site disruption, benefits to servicing and other follow-on trades, increased safety on-site and protection of environment. The off-side application is increasing due to the mentioned advantages, see [9]. The intumescence may be described as the reaction of active components under of influence of heat to produce significant swelling. The intumescents expands to many times their initial thickness in fire and produce carbonaceous char, which provides a thermal protective layer to any surface to which coating has been applied. Intumescent painting comprises usually a catalyst, which decomposes produce a mineral acid, a carbonific, such as starch, a binder or a resin, which softens at a predetermined temperature, and a spumific agent, which decomposed with melting of the binder. The thin film intumescent coatings are designed for internal use and typically have a dry film thickness no grater than 5 mm. They protect the steelwork for fire resistance period from 30 min till 120 min; mostly asked is 60 min. For external exposure is in the thin coatings the intumescent base coat protected by special sealer coat and decorative coat. Intumescent coating system is usually spry applied, but the application may be by brush or roller also.

The bolted structural steelwork connections with the off-site applied intumescent coatings need on-site completing of coatings of bolts after erecting of steelwork. Due to reduction in temperature in the region of connection compare to connected elements, the built up of intumescent char on the connected ply shield the fire unprotected bolts sufficiently to provide adequate fire resistance. The presented paper is directed to the influence of the shielding in time and the possibility of prediction the temperature in connection by the step by step procedure, see [8].

2. EXPERIMENTS

Three tests were performed to study the influence of fire protection of bolts in connection protected by intumescent coating. The test set up consists of stub with beam to column fin plate connection, see Fig. 1. Two stubs were installed by each test, one with painted bolts and second one with bolts without coating. The intumescent coating was prepared off-site three weeks before testing according to the operations and maintenance manual by the producer by an accredited company specialised to the fire protection finishes. The thickness of coating was tested by calibrated instrument working on the electro-magnetic induction principle. The treated part of the bolt went beyond the nut 20 mm. The tests were performed in the laboratory PAVUS a.s. in Veselí nad Lužnicí; No. 1 October 20, 2004; No. 2 May 25, 2005, see [10], and No. 3 November 11, 2005. In the second test the whole fin plate was left unprotected. First two tests were heated in the furnace following the fire curve measured during the seventh large fire test in Cardington, see [1]. During third test simulates the gas temperature nominal fire curve. The Fig. 2 shows the test set up in test No. 2 before...
and after the fire test with foamed coating, see [9], and the position of the thermocouples in test No. 3. The gas temperatures as well as the average measured temperatures in connection with protected and unprotected bolts are summarised in Tab. 1 for test No. 3. The thermocouples were placed in bolts heads and in plate, 25 mm horizontally from the centre of the bolt hole, 16 thermocouples for a test. No difference in the temperature of bolts and of plate was found in case of protected bolts. For unprotected bolt the increase of the temperature of the bolts compare to the plate reached 28 °C, which is about 8 %.

![Fig. 1 – Test set up, position of thermocouples](image1)

Fig. 1 – Experiment with the fire unprotected bolts in fire protected joint
a) set up before test, b) the joint with intumescent paint after foaming; test No. 2

![Fig. 2b – a) Test set up No. 3 before test with and without fire protected bolts; b) position of the thermocouples in bolt head and plate](image2)

*Fig. 2b – a) Test set up No. 3 before test with and without fire protected bolts; b) position of the thermocouples in bolt head and plate*
Fig. 3 – Measured temperatures in fin plate connection, test No. 3

Fig. 4 – Average measured temperatures in fin plate connection, test No. 3

Tab. 1 – Average measured temperatures in fin plate connection during the test No. 3

<table>
<thead>
<tr>
<th>Time, min</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>102</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average measured gas temperature, °C</td>
<td>12</td>
<td>779</td>
<td>840</td>
<td>990</td>
<td>977</td>
<td>1016</td>
<td>1098</td>
<td>1043</td>
</tr>
<tr>
<td>Protected bolts, °C</td>
<td>11</td>
<td>302</td>
<td>408</td>
<td>553</td>
<td>674</td>
<td>763</td>
<td>863</td>
<td>931</td>
</tr>
<tr>
<td>Plate by protected bolts, °C</td>
<td>11</td>
<td>300</td>
<td>406</td>
<td>552</td>
<td>675</td>
<td>767</td>
<td>867</td>
<td>940</td>
</tr>
<tr>
<td>Unprotected bolts, °C</td>
<td>11</td>
<td>359</td>
<td>486</td>
<td>643</td>
<td>743</td>
<td>840</td>
<td>943</td>
<td>999</td>
</tr>
<tr>
<td>Plate by unprotected bolts, °C</td>
<td>11</td>
<td>331</td>
<td>467</td>
<td>635</td>
<td>749</td>
<td>840</td>
<td>949</td>
<td>1012</td>
</tr>
<tr>
<td>Connection temperature, protected bolts, °C</td>
<td>11</td>
<td>301</td>
<td>407</td>
<td>553</td>
<td>675</td>
<td>765</td>
<td>865</td>
<td>936</td>
</tr>
<tr>
<td>Connection temperature, unprotected bolts, °C</td>
<td>11</td>
<td>343</td>
<td>475</td>
<td>639</td>
<td>746</td>
<td>840</td>
<td>946</td>
<td>1006</td>
</tr>
<tr>
<td>Difference of temp. (bolt minus plate), protect. bolts, °C</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>-4</td>
<td>-4</td>
<td>-9</td>
</tr>
<tr>
<td>Difference of temp. (bolt to plate), protect. bolts, %</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Difference of temp. (bolt minus plate), unprotected bolts, °C</td>
<td>0</td>
<td>28</td>
<td>19</td>
<td>8</td>
<td>-6</td>
<td>0</td>
<td>-6</td>
<td>-13</td>
</tr>
<tr>
<td>Difference of temp. (bolt to plate), unprotected bolts, %</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Increase of temperature (unprotect./protect. bolts) in %</td>
<td>0</td>
<td>14</td>
<td>17</td>
<td>16</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>
3. ANALYTICAL PREDICTION

The temperature of a joint may be assessed using the local $A/V$ value of the parts forming that joint, see Annex D of EN 1993-1-2 [6]. In the case of the presented test set up is the section factor for the whole set up $A_{set}/V_{set} = 188 \text{ m}^{-1}$, for fin plate only $A_{fin}/V_{fin} = 349 \text{ m}^{-1}$; and for fin plate and beam web $A_{web}/V_{web} = 212 \text{ m}^{-1}$. As a simplification a uniform distributed temperature may be assessed within the joint. In this case the temperature may be calculated using the maximum value of the ratios $A/V$ of the connected steel members in the vicinity of the joint. For connected beam is the section factor $A_{b}/V_{b} = 303 \text{ m}^{-1}$.

The thermal properties of the fire protection material after foaming were measured as about $\rho_p = 200 \text{ kg m}^{-3}$, specific heat $c_p = 1200 \text{ J kg}^{-1} \text{ K}^{-1}$ and thermal conductivity $\lambda_p = 0.1 \text{ W m}^{-1} \text{ K}^{-1}$. The thickness of the coating after foaming was expected from the first and second tests as $d_p = 6.5 \text{ mm}$, see [8]. The temperature of connection was calculated based on the step by step prediction method for unprotected internal steelwork, eq. (4.25) in standard [6]. The results may be observed in Fig. 5, where is also demonstrated the prediction of the temperature using the step by step method for fire protected steelwork according to eq. (4.27) in document [6] with the section factor for the whole tests set up. The prediction is good and conservative for protected as well as unprotected bolts till the end of the test in 105 min. The influence of calculation of the section factor by selected sections is demonstrated in Fig. 6.

The tests show that the estimation of the section factor of the fin plate by $2000/ t_p = 333 \text{ m}^{-1}$, where $t_p$ is the fin plate thickness, is conservative. The equation $A/V = 1200/t_p$ is representing the current situation and is covering the influence of unprotected bolts in protected connection. The estimation of the temperature is valid even for the connection with unprotected fin plate, see Fig. 7.

![Graph showing temperature comparison](image)

Fig. 5  – Comparison of the predicted temperature in connection to measured values in case of the protected and unprotected bolts, test No. 3
Gas temperature

Protected bolts in protected connection average measured

Prediction of protected connection section of fin plate only $A_{fin}/V_{fin} = 349 \text{ m}^{-1}$

Prediction of protected connection section of web and plate $A_{web}/V_{web} = 212 \text{ m}^{-1}$

Prediction of protected connection section of beam $A_b/V_b = 303 \text{ m}^{-1}$

Unprotected bolts in protected connection, average measured

Afin /Vfin = 349 m-1

Aweb /Vweb = 212 m-1

Ab /Vb = 303 m-1

Fig. 6 – Comparison of predicted temperature in connection by section factors of the parts forming the connection to the measured values, test No. 3

Fig. 7 – Comparison of predicted temperature in connection by section factors of the parts forming that connection to the measured values, test No. 2

4. CONCLUSIONS

The bolted fin plate connection fire protected by intumescent coating with unprotected bolts showed till 17% higher temperature compare to the connection with protected bolts.

The test shows a conservative estimation of the connection temperature according to European standard by analytical perdition model based on the section factor of the connected member and estimated material properties of expanded coating. The conservative prediction by section factor is covering also the increase of temperature due to unprotected bolt.
To extend the result of presented tests by a FE study, which is directed to the influence of the fire scenario and to the connection geometry/type to the temperature of the connection with the fire unprotected bolts in the fire protected connection, is under preparation.

ACKNOWLEDGEMENT

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REFERENCES