THERMAL BEHAVIOUR OF REACTION INTUMESCENT PAINT USED FOR PASSIVE PROTECTION OF STEEL STRUCTURES

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Abstract

Steel structures often need some passive protection measures for the validation of national and international regulations. These regulations present standard and simplified methods for the design of steel structures when exposed to fire conditions. One of this formulae presented in Eurocode 3 has been determined based on simplified hypothesis for material protection behaviour, considering uniform temperature distribution across steel section, constant thermal conductivity and constant thickness for material insulation. This work presents preliminary experimental tests for determining the thermal insulation behaviour (thermal conductivity) as function of the mean insulation temperature evolution [1]. Specimens have been coated and heated with slow heating rate, 800 [ºC/h], and temperatures have been recorded on steelwork IPE100 profiles. Results are in good agreement with other numerical simulations proposed by Tan et al for other intumescent protection system [2].

Introduction

Applying intumescent coatings, as fire protection to steel structures, is normally function of the structural element section factor and also function of the time request for fire design resistance. This design procedure is normally dependent on the critical temperature. Temperature time analysis for insulated steelwork may be used based on the assumption of uniform temperature distribution over the entire steel member [3].

Two distinct steel specimens have been prepared with two hand coats of the same protection material PROTHERM 7G-950. Temperatures have been measured on the steel element beam and near the thermal action conducting experiments. These results may be used in accordance with analytical thermal simplification to determine thermal conductivity for the insulation material in accordance to the reference document [4].

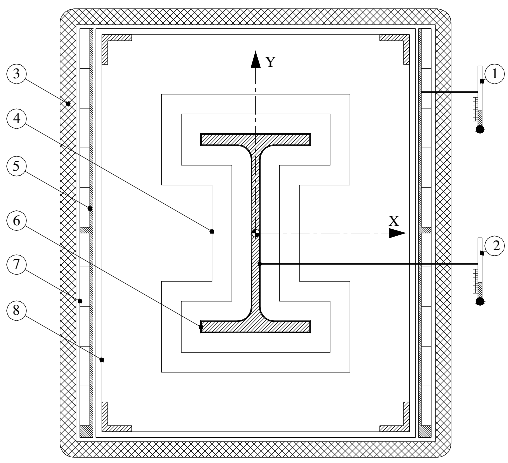
Experimental setup

Two distinct steel specimens have been prepared with two hand coats with a drying time between coats of 24 [h] and a full cure of the same time. Both specimens present approximately a dry thickness of 0.8 [mm]. Each specimen steel member has 630 [mm] length, obtained from the main steel profile S235 supplier. Around those specimens a steel frame box was specially prepared for heating propose. Because this insulation material is thermal reactive, a chemical reaction will be function of temperature condition and the shape of the protection material will change during time experiment, as represented in figure 1. The use of primer is a condition for stable adhesion of intumescent paint.

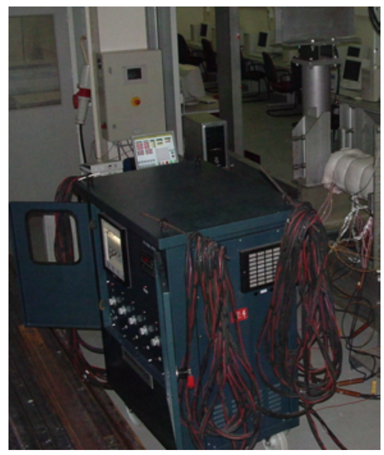
Figure 1 - Intumescent paint increasing thickness.

An electro ceramic heat procedure (7), based on a heating power unit of 70 kVA was applied to each specimen (6) and thermocouples (1,2) were positioned over the beam and over the steel frame box (8), as represented in the next figure.

a) Setting specimen inside steel frame box.



b) Schematics for experiments.



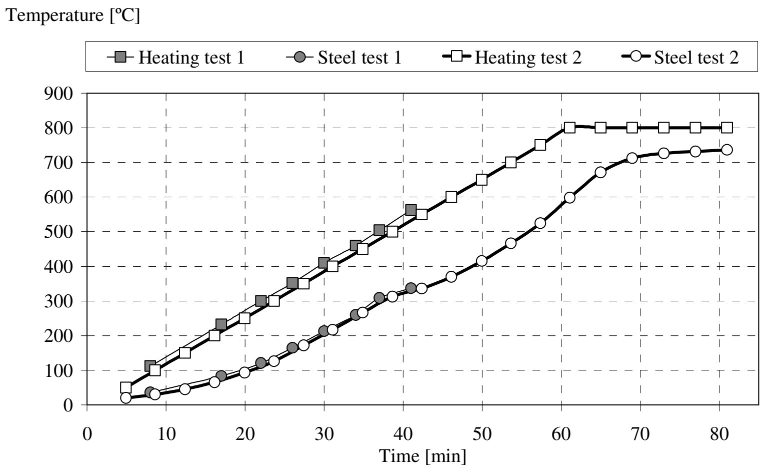
c) Heating power unit.

Figure 2 – Experimental setup for heating procedure.

For increasing thermal efficiency, thermal insulation fiber material (3) was positioned around the steel box, composed with a steel plate material (5) and other equal leg angle profiles.
During experiments, the intumescent paint increases its thickness (4), as expected, protecting steel from the elevated temperature effect.

Experimental results

Temperatures were measured over the beam and also over the steel frame box for several time steps. The first test was conducted inside laboratory without any type of ventilation conditions, limiting the time of the experiment. The second test was conducted outside laboratory space, allowing for a longer measuring data result, as represented in figure 3.



a) Experimental temperature measuring results. b) Final stage test 1.

Figure 3 – Experimental results.

Analytical approach for thermal conductivity

According to the Eurocode 3 formulae, the result of the heat differential equation is based on a unidimesional heat transfer, assuming uniform temperature distribution over the insulation and steel. This may result in temperature increments for insulation steel members during time interval Δt.

$$\Delta\theta_{a,t} = \left[\frac{\lambda_{p,t}/d_p}{C_a\ \rho_a}\times\frac{A_p}{V}\times\left(\frac{1}{1+\phi/3}\right)\times(\theta_t-\theta_{a,t})\Delta t\right]-\left[\left(e^{\phi/10}-1\right)\Delta\theta_t\right] \quad \text{with} \quad \phi=\frac{C_p\rho_p}{C_a\rho_a}\times d_p\times\frac{A_p}{V} \qquad \text{(eq.1)}$$

In this expression A_p/V is the section factor for steel members insulated by fire protection material, C_a and ρ_a represent the temperature dependant specific heat and the constant specific mass of steel, C_p and ρ_p are the specific heat and the specific mass for the protection material, while d_p and $\lambda_{p,t}$ accounts for the dry thickness and conductivity of the protection material. θ_t and $\theta_{a,t}$ represent the heat source and steel temperature, respectively.

The inverse of this equation may explicit thermal conductivity, according to temperature measured results on beam and on the heating source. This may lead to the following expression:

$$\lambda_{p,t}(t)=\left[d_p\times\frac{V}{A_p}\times C_a\ \rho_a\times(1+\phi/3)\times\frac{1}{(\theta_t-\theta_{a,t})\Delta t}\right]\times\left[\Delta\theta_{a,t}+\left(e^{\phi/10}-1\right)\Delta\theta_t\right] \qquad \text{(eq.2)}$$

Temperature of the protection material, θ_p, may be approximated by the average value of the heating source and steel temperature, [4].

Using the experimental results and equation 2, thermal conductivity may be determined for the insulation material temperature, see figure 4.

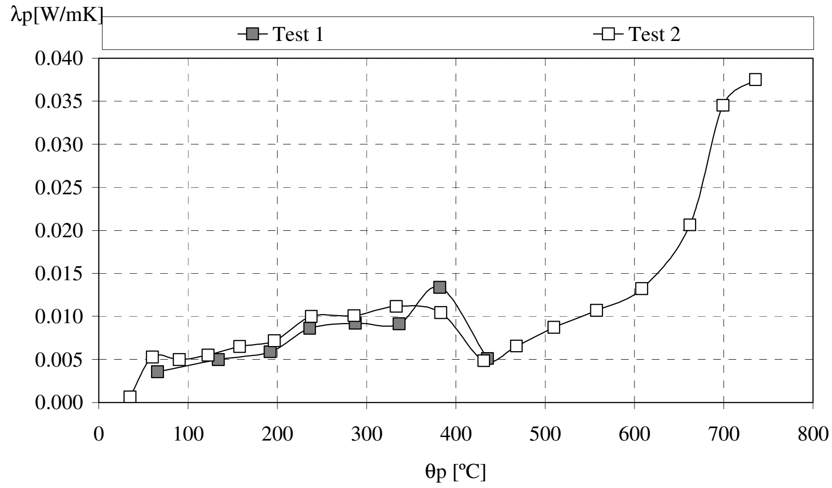


Figure 4 – Thermal conductivity for insulation material.

For the range of insulation temperature conditions, the conductivity is temperature dependent. The shape and the resulting values are in accordance with other reported results for different intumescent material [2].

Conclusions and discussion

These experiments represent a preliminary study of protected steel structures exposed to fire condition. The main objective was to determine thermal conductivity for this type of insulation reaction material, because most part of design codes and regulations consider this property as temperature independent. New formulae should arise for determining temperature of steel when insulated with intumescent paint.

Two experiments were conducted with the same conditions, reproducing similar results. More experiments are being produced with different thickness protection material and with mechanical loading conditions.

References

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