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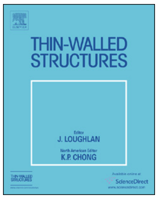

Predicting intumescent coating protected steel temperature in fire using constant thermal conductivity

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ABSTRACT

This paper presents the results of a study to investigate the feasibility of using a constant thermal conductivity for intumescent coating when calculating protected steel temperature in fire, based on analysing a series of fire tests on intumescent coating protected steel sections with a range of section factors and intumescent coating thicknesses. Having a constant thermal conductivity enables simplified analytical equations to be developed for design purpose. The constant thermal conductivity is calculated as the temperature averaged value within the temperature range of interest for fire resistance design. The constant thermal conductivity is then used to calculate the protected steel temperatures and the calculated steel temperatures are compared with the measured values from the fire tests. The results of this comparison suggest that it is feasible to use a constant thermal conductivity for intumescent coating. The constant thermal conductivity value would be dependent on the intumescent coating thickness and the steel section factor. However, this issue may be dealt with by obtaining the intumescent coating thermal conductivity from fire tests on steel plates, because a comparison between results based on steel plate fire tests and those based on steel section fire tests shows close agreement. The results also indicate that the constant thermal conductivity of intumescent coating converges to a fixed value, independent of the steel section factor, when the steel section factor is high, suggesting that the constant thermal conductivity method is particularly applicable to thin-walled sections with high section factors.

1. Introduction

Structural steel is widely used in modern building construction where fire safety is one of the fundamental safety requirements. Due to the very high thermal conductivity of steel, steel sections, particularly thin-walled steel sections, often require fire protection to delay the temperature rise of steel when exposed to fire. Thin film intumescent coatings are now becoming the dominant choice for passive fire protective materials for steel structures owing to their many advantages including: flexibility and ease of usage for both on- and offsite applications, light-weight, thin and attractive appearance, and high standard finish.

To assess the safety of steel building structures in fire, the temperature of the steel components must be evaluated beforehand. To enable calculation of temperature of protected steel in fire, the thermal conductivity of the fire protection (insulation) material used has to be determined. As a thermally reactive material for fire protection of steel components, intumescent coating is designed to expand up to 100 times its initial thickness under high temperatures to form a porous char structure, thereby providing the necessary insulation function to the substrate. The physical expansion/chemical reaction process of intumescent coating is complex. To date, there is no reliable model to predict the expansion process of intumescent coating. Many models [1–13] for predicting intumescent coating protected steel temperatures assume intumescent coating expansion. Recently, Zhang et al [14–16] made an attempt to predict intumescent coating expansion by assuming expansion to be linked to the amount of gases released during the expansion process. Although they have achieved some success, based on their comparisons of prediction and fire test results, too many input data are necessary for the model, including the chemical kinetic properties and several other physical properties of the coating that are difficult to quantify directly.

The current Eurocode assessment method for intumescent coating [17] treats intumescent coating as a non-reactive material and determines temperature-dependent thermal conductivity of intumescent coating (to be explained in more detail in Section 2 of this paper), based on fire test results. Whilst this method is simple to

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apply, it cannot be used to include the effects of intumescent coating thickness and steel section factor on intumescent coating thermal conductivity because this method outputs a single temperature-dependent thermal conductivity curve.

However, if a temperature-independent constant thermal conductivity for intumescent coating can be used, then a regression equation can be developed to consider the effects of intumescent coating thickness and steel section factor. This is the motivation of this research. Furthermore, if a constant thermal conductivity can be used, simplified analytical method can be developed to calculate steel temperature and to estimate the required intumescent coating fire protection thickness.

2. Theoretical basis of constant thermal conductivity of intumescent coating

2.1. Temperature calculation for protected steel element

According to Eurocode 1 (EN 1991-1-2) [18,19], the temperature of protected steel can be calculated using the following equation:

$$\Delta T_s = \frac{(T_g - T_s)A_p/V}{(d_p/\lambda)c_s\rho_s\left(1+\frac{1}{3}\phi\right)}\Delta t - \left(e^{\phi/10} - 1\right)\Delta T_g \tag{1}$$

Table 1
Details of all test specimens.

Specimen ID*	Specimen type	Section factor A_p/V (m^{-1})	Target DFT (mm)	Average measured DFT (mm)	Type of coating (T/L)
A03T1	Steel plate	125.0	0.3	0.323	T
A03T2	Steel plate	125.0	0.3	0.330	T
A07T1	Steel plate	125.0	0.7	0.761	T
A07T2	Steel plate	125.0	0.7	0.760	T
A07T3	Steel plate	125.0	0.7	0.711	T
A07T4	Steel plate	125.0	0.7	0.750	T
A07T5	Steel plate	125.0	0.7	0.701	T
A07T6	Steel plate	125.0	0.7	0.795	T
A22T1	Steel plate	125.0	2.2	2.245	T
A22T2	Steel plate	125.0	2.2	2.249	T
A22T3	Steel plate	125.0	2.2	2.250	T
A29T1	Steel plate	125.0	2.9	2.810	T
A29T2	Steel plate	125.0	2.9	3.110	T
A29T3	Steel plate	125.0	2.9	3.085	T
B03T1	I-shaped section	142.1	0.3	0.296	T
B07T1	I-shaped section	142.1	0.7	0.792	T
B07T2	I-shaped section	142.1	0.7	0.802	T
B07T3	I-shaped section	142.1	0.7	0.761	T
B07T4	I-shaped section	142.1	0.7	0.818	T
B07T5	I-shaped section	142.1	0.7	0.797	T
B22T1	I-shaped section	142.1	2.2	2.210	T
B22T2	I-shaped section	142.1	2.2	2.340	T
B29T1	I-shaped section	142.1	2.9	2.932	T
C03T1	C-shaped section	155.3	0.3	0.282	T
C07T1	C-shaped section	155.3	0.7	0.709	T
C07T2	C-shaped section	155.3	0.7	0.763	T
C07T3	C-shaped section	155.3	0.7	0.817	T
C07T4	C-shaped section	155.3	0.7	0.790	T
C07T5	C-shaped section	155.3	0.7	0.803	T
C22T1	C-shaped section	155.3	2.2	2.156	T
C22T2	C-shaped section	155.3	2.2	2.071	T
C29T1	C-shaped section	155.3	2.9	2.876	T
D06L1	Steel Plate	142.5	0.6	0.626	L
D09L1	Steel Plate	142.5	0.9	0.897	L
D15L1	Steel Plate	142.5	1.5	1.548	L
E06L1	H-shaped section	145.7	0.6	0.620	T
E06L2	H-shaped section	145.7	0.6	0.626	T
E06L3	H-shaped section	145.7	0.6	0.613	T
E09L1	H-shaped section	145.7	0.9	0.920	T
E09L2	H-shaped section	145.7	0.9	0.856	T
E09L3	H-shaped section	145.7	0.9	0.872	T
E15L1	H-shaped section	145.7	1.5	1.476	T
E15L2	H-shaped section	145.7	1.5	1.577	T
E15L3	H-shaped section	145.7	1.5	1.483	T
F06L1	H-shaped section	114.0	0.6	0.674	T
F06L2	H-shaped section	114.0	0.6	0.607	T
F06L3	H-shaped section	114.0	0.6	0.571	T
F09L1	H-shaped section	114.0	0.9	0.804	T
F09L2	H-shaped section	114.0	0.9	0.804	T
F09L3	H-shaped section	114.0	0.9	0.807	T
F15L1	H-shaped section	114.0	1.5	1.262	T
F15L2	H-shaped section	114.0	1.5	1.337	T
F15L3	H-shaped section	114.0	1.5	1.309	T

** Specimen type: A: steel plate, B: hot rolled I-shaped section, C: hot rolled channel-shaped section, D: steel plate section (full protected with intumescent coating), E: welding H-shaped section-1, F: welding H-shaped section-2.

* Sample ID=specimen type **+target DFT+type of coating+sample number.