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Furnace tests on unprotected and protected concrete filled structural hollow sections

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ABSTRACT

The accurate prediction of cross-sectional temperatures within concrete filled steel hollow (CFS) sections is critical for the accurate prediction of fire resistance. Whilst there have been many thermal and structural tests conducted on CFS columns, there are few that report the full cross-sectional thermal profile, and when they are reported, the sensor density is low, hindering the ability to validate models. This paper presents furnace tests and thermal modelling on 14 unprotected and 20 protected CFS sections, and examines the effect of several parameters on cross-sectional thermal profiles, as well as assessing the accuracy of both Eurocode thermal analysis guidance and intumescent fire protection design guidance. This paper shows that; (a) the assumptions within the Eurocode guidance can lead to large over-estimations in cross-sectional temperatures; (b) proposes new thermal modelling assumptions in three key areas; and (c) shows that the current intumescent fire protection design guidance is very conservative.

1. Introduction

Architects and engineers increasingly specify concrete filled steel hollow structural sections (CFS) in the design and construction of multi-storey buildings. CFS sections consist of hollow steel sections that are in-filled with concrete to provide superior load carrying capacity and structural fire resistance as compared with unfilled steel tubes. They are an attractive and efficient means by which to design and construct compressive members in highly optimised structural frames. The concrete infill and the steel tube work together, at both ambient temperatures and during fire; the steel tube acts as stay-in-place formwork during casting of the concrete, thus reducing forming and stripping costs, and provides a smooth, rugged, architectural surface finish; the concrete infill enhances the steel tube's resistance to local buckling; and the steel tube sheds axial load to the concrete core when heated during a fire, thus enhancing the fire resistance of the column [1].

Multi-storey buildings may require structural fire resistance ratings of two hours or more [2] that CFS sections can often provide without the need for applied fire protection. However, when a structural fire resistance assessment [1,3–6] shows that adequate fire resistance is unachievable without insulation, external fire protection must be applied (in the UK the preferred method of fire protection is often by intumescent coatings).

The structural performance of CFS sections fundamentally depends on the temperatures that the steel tube, internal steel reinforcement (when present) and concrete core experience during fire and after cooling [7]. Prediction of internal temperatures is thus critical to determine the amount and effectiveness of protection needed to achieve a given fire resistance. There is, however, a paucity of detailed thermal data from standard furnace tests available in the literature for both protected and unprotected CFS sections in fire. A global review of structural furnace tests [8] showed that of the 300+ available tests, only 75 included protection; 24 of these were protected with intumescent coatings and only 18 of these were tested within the past 20 years.

Furnace tests on unprotected CFS columns reported in the literature rarely report detailed cross-sectional temperatures, and there are no data available on performance during the cooling phase. Test reports that do include full temperature profiles typically have inadequate sensor density; for example tests presented in [9] and [10] measured only one steel and two concrete temperatures for each specimen, hindering their use for model

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validation.

Various attempts at thermal model validations have been presented previously in the literature. For example, Tao and Ghannam [11] used data from available standard furnace tests to predict the temperature profiles within CFS sections using a finite element model and suggested possible improvements over the Eurocode's [4] prescribed modelling approaches. However, Tao and Ghannam also noted that the variable emissivity of the steel tube, the moisture content of the infill concrete, and the gap conductance at the steel tube–concrete core interface played potentially important roles in the heat transfer in CFS columns. Han et al. [12] presented and modelled the temperature profiles within unprotected and protected CFS columns during 12 furnace tests, although again the density of temperature measurement was low. These tests demonstrated that the spray applied passive fire protection materials used were effective at preventing heat transfer; they also demonstrated that it was possible to predict the steel tube temperatures of the protected CFS sections with reasonable accuracy. However, predicting temperatures in CFS sections protected with intumescent coatings continues to prove difficult [12] due to the chemical and physical changes they undergo during heating, foaming, and charring [13].

To increase the available data on protected CFS columns under standard fire testing, this paper presents results and analysis of 34 unloaded furnace tests on both unprotected and protected CFS columns of various shapes and sizes, providing temperature data throughout the heating and cooling phases of standard fire exposure. These data will allow thermal modelling approaches to be created and verified, and aims to demonstrate an ability to credibly predict the performance of CFS sections with intumescent fire protection.

2. Furnace tests

The furnace test program was carried out in ceramic lined

Table 1
Testing matrix.

Test no.[a]		Shape[b]	Size (b OR d)	t_a	Fill[c]	Fire[d]	Reactive coating					
								Section factor			DFT (mm)[g]	
			(mm)	(mm)			Type[e]	F.R.[f] (min)	$t_{a,e}$ (mm)	H_p/A_{eff} (m^{-1})	Design	Applied
1	C-3-3-F-I-N	C	323.9	10	F	I	N	N/A				
2	C-3-2-F-I-N	C	323.9	8	F	I	N					
3	C-2-3-F-I-N	C	219.1	5	F	I	N					
4	C-2-2-F-I-N	C	219.1	8	F	I	N					
5	C-2-1-F-I-N	C	219.1	10	F	I	N					
6	C-1-3-F-I-N	C	139.7	10	F	I	N					
7	C-1-2-F-I-N	C	139.7	8	F	I	N					
8	C-1-1-H-I-N	C	139.7	5	H	I	N					
9	C-1-1-F-I-N	C	139.7	5	F	I	N					
10	S-3-3-F-I-N	S	300	10	F	I	N					
11	S-1-3-F-I-N	S	120	10	F	I	N					
12	S-1-1-F-I-N	S	120	5	F	I	N					
13	C-1-1-F-S-N	C	139.7	5	F	S	N					
14	S-1-1-F-S-N	S	120	5	F	S	N					
15	C-3-3-F-I-C1a	C	323.9	10	F	I	C1	90	27.1	36.9	3.39	3.50
16	C-3-3-F-I-C1b	C	323.9	10	F	I	C1	90	27.1	36.9	3.39	3.60
17	C-3-2-F-I-C1	C	323.9	8	F	I	C1	90	25.1	39.9	3.43	3.48
18	C-2-3-F-I-C1	C	219.1	5	F	I	C1	90	22.1	45.3	3.48	3.50
19	C-2-2-F-I-C1	C	219.1	8	F	I	C1	90	25.1	39.9	3.43	3.50
20	C-2-1-F-I-C1	C	219.1	10	F	I	C1	90	27.1	36.9	3.43	3.55
21	C-1-3-F-I-C1	C	139.7	10	F	I	C1	90	27.1	36.9	3.48	3.53
22	C-1-2-F-I-C1	C	139.7	8	F	I	C1	90	25.1	39.9	3.48	3.52
23	C-1-1-F-I-C1	C	139.7	5	F	I	C1	90	22.1	45.3	3.48	3.51
24	C-1-1-H-I-C1	C	139.7	5	H	I	C1	90	22.1	45.3	3.48	3.53
25	S-3-3-F-I-C1	S	300	10	F	I	C1	90	27.1	36.9	3.39	3.53
26	S-1-1-F-I-C1	S	120	5	F	I	C1	90	21.5	46.5	3.48	3.49
27	C-1-1-F-I-C1.14D	C	139.7	5	F	I	C1	90	22.1	45.3	3.48	3.53
28	C-1-1-F-I-C1.28D	C	139.7	5	F	I	C1	90	22.1	45.3	3.48	3.53
29	C-1-1-F-I-C1.75	C	139.7	5	F	I	C1	75	20.6	48.6	2.10	2.00
30	C-1-1-F-I-C1.120	C	139.7	5	F	I	C1	120	24.5	40.9	4.00	4.06
31	C-1-1-F-S-C1	C	139.7	5	F	S	C1	90	22.1	45.3	3.48	3.53
32	S-1-1-F-S-C1	S	120	5	F	S	C1	90	21.5	46.5	3.48	3.41
33	C-3-3-F-I-C2	C	323.9	10	F	I	C2	90	27.1	36.9	2.94	2.94
34	S-3-3-F-I-C2	S	300	10	F	I	C2	90	27.1	36.9	2.94	3.11

[a] test numbering system Shape – size – wall thickness- fill type – fire insult –protection type.
[b] *C*=circle, *S*=square.
[c] *H*=high strength concrete (HSC), *F*=fibre reinforced concrete (FIB).
[d] I=*ISO 834* standard fire insult [15], S=smouldering curve [16].
[e] *N*=unprotected, *C1*=Interchar1120, *C2*=Interchar212.
[f] *F.R.*=required fire resistance based on steel limiting temperature of 520 °C.
[g] DFT=dry film thickness.