

METHODS OF SPECIFYING INTUMESCENT COATING ON CONCRETE FILLED STEEL TUBULAR SECTIONS

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Layout of presentation

- Decision on tests' specifications (e.g. section sizes, DFT, number of tests, Conducting the fire tests on a total number of 48 specimens) ;
- A conversion program ;
- Generating DFT tables for each product ;
- FireSoft validation against ABAQUS ;
- Determining effective thermal conductivity to be used in FireSoft ;
- Consistency check of the evaluated thermal conductivity with final DFT tables;
- Accuracy check of the available formulations.

Overview on specimens for each parts of the project

First part of the project

Circular hollow section	External diameter (mm)	Wall thickness(mm)	Decided DFT Coatings	Length (mm)	Number
CHS 219.1	219.1	6.3	Min/Mid/Max	1000	3
CHS 219.1	219.1	16	Min/Mid/Max	1000	3
CHS 273	273	6.3	Min/Max	1000	2
CHS 273	273	16	Min/Max	1000	2
CHS 323.9	323.9	8	Min/Mid/Max	1000	3
CHS 323.9	323.9	16	Min/Mid/Max	1000	3
Total					16

Second part of the project

Circular hollow section	External diameter (mm)	Wall thickness(mm)	Decided DFT Coatings	Length (mm)	Number
CHS 219.1	219.1	6.3	Min/Max	1000	2
CHS 219.1	219.1	16	Min/Max	1000	2
CHS 323.9	323.9	8	Min/Max	1000	2
CHS 323.9	323.9	16	Min/Max	1000	2
Total					8

Test Procedure- Instrumentation-

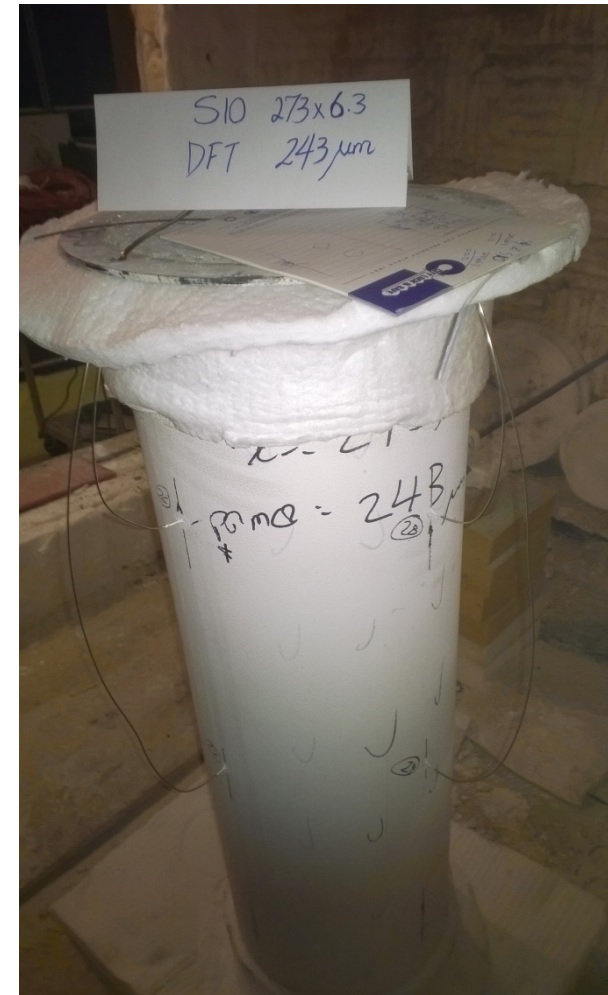
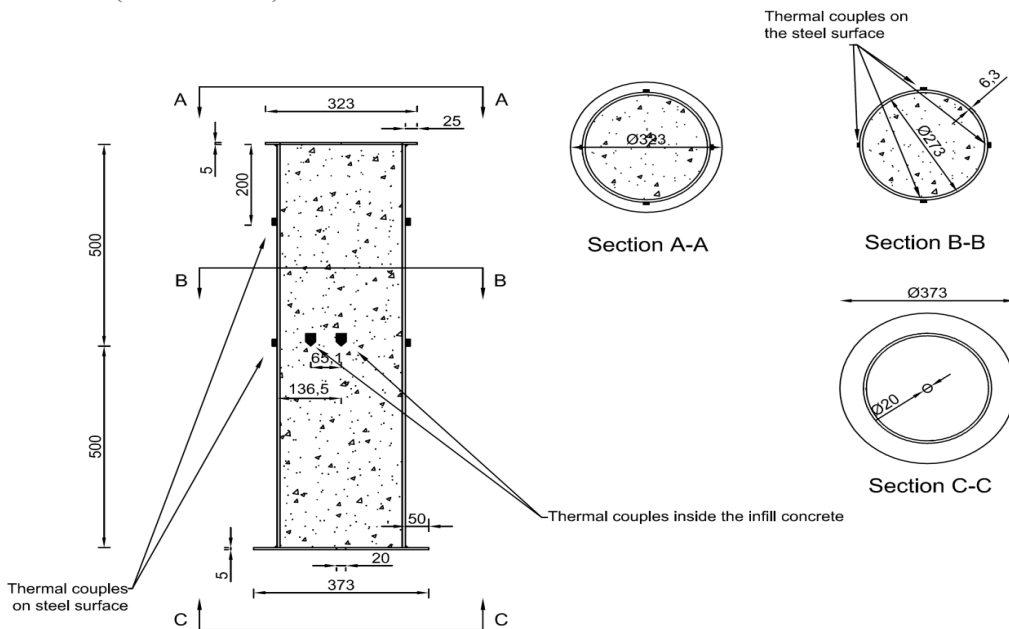
• Locations of thermocouples (BS EN 13381-8:2013 –Figure 7)

Thermocouples on steel

Totally 8 thermal couples : 4 thermocouples 200mm from top of the section
4 thermocouples 500mm from top (mid height) of the section

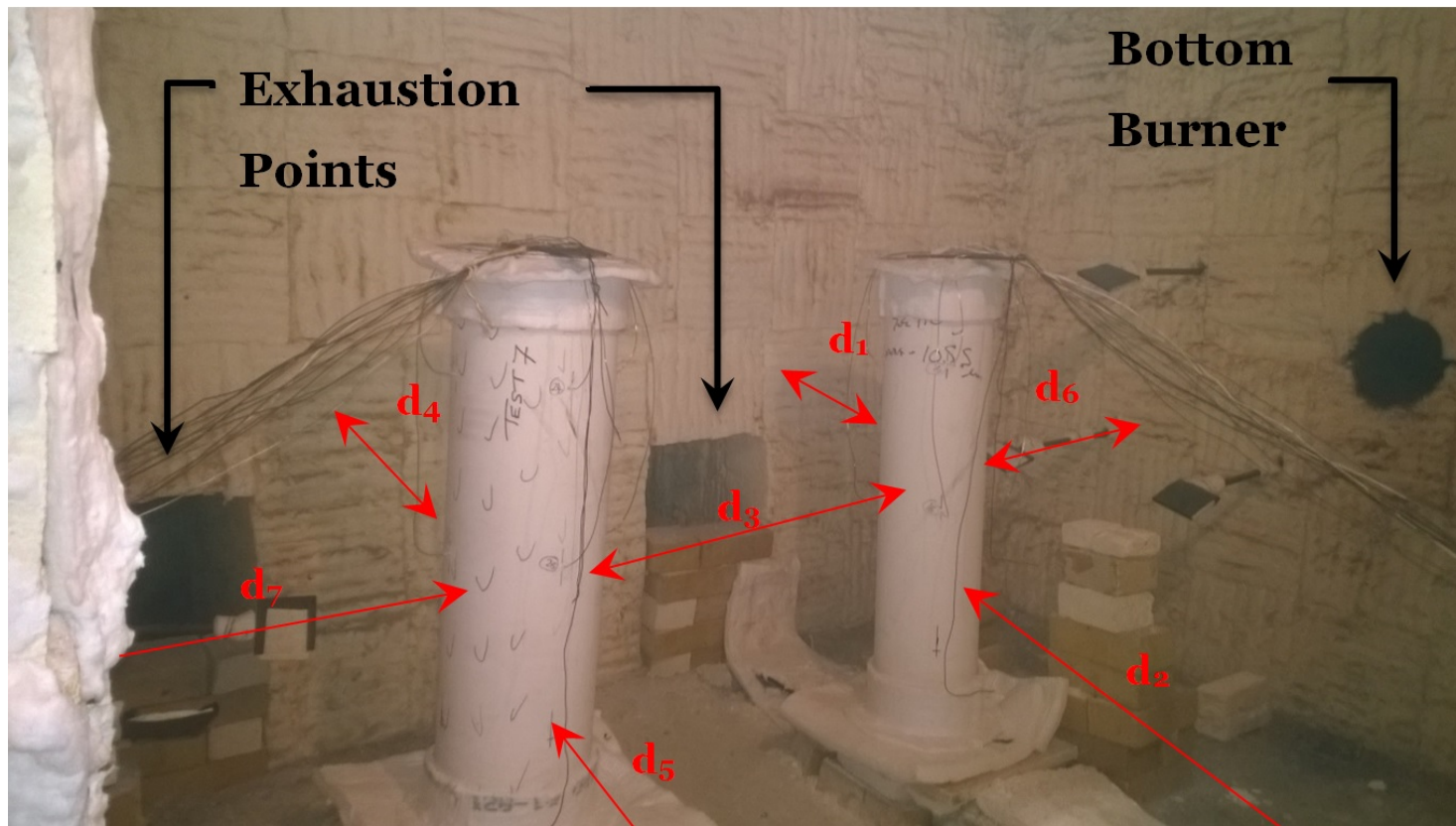
Thermocouples in infill-concrete

Totally 2 thermocouples : 1 in the center of the section (i.e. $0.5 \times \text{Diameter}$)
1 on half way between center and internal wall of the section (i.e. $0.25 \times \text{Diameter}$)



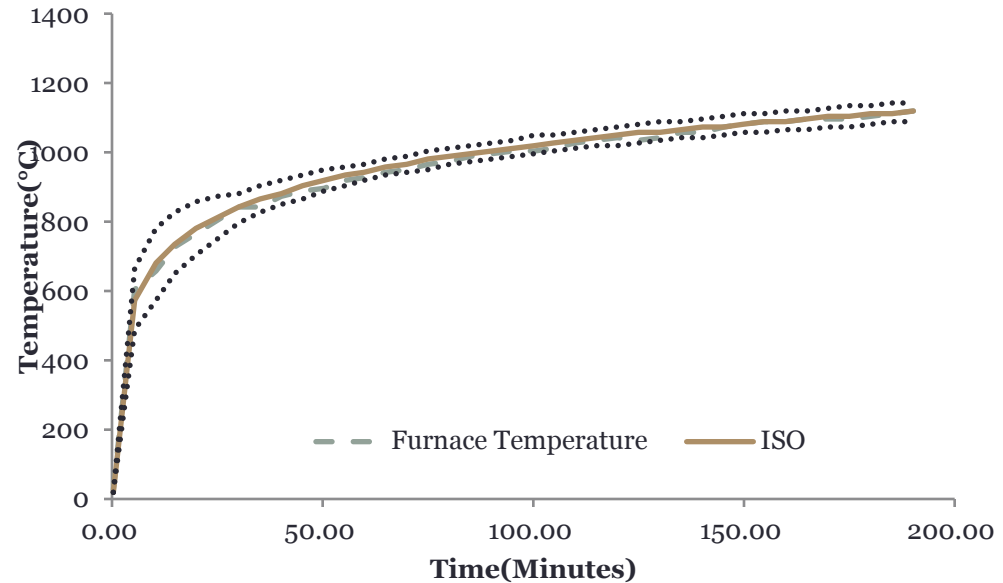
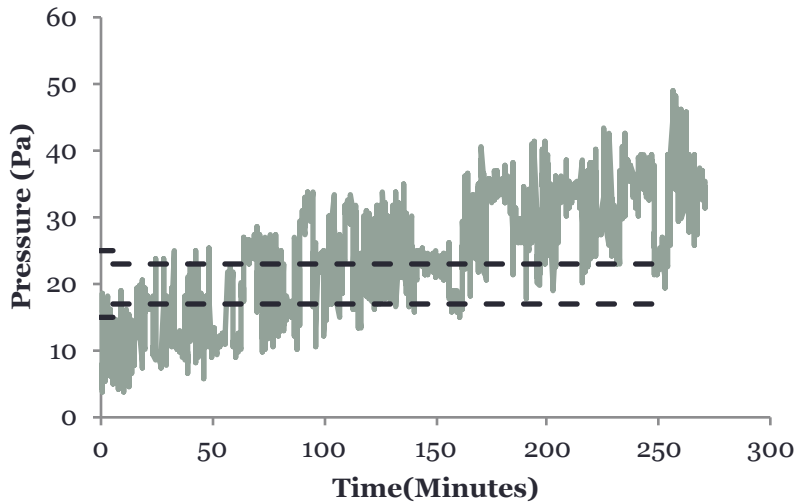
Test Procedure- Instrumentation

- Locations of test specimens inside the furnace



Test Procedure- Controlling furnace temperature

- Typical recorded furnace temperatures



Conversion software -



Conversion-Program-FD7.xlsm - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Developer Add-Ins

Times New Roman - 12 - A A Cut Paste Copy Paste Format Painter Clipboard

General Wrap Text Normal 6 Output Gen... Note 2

Font Alignment Number

AU24

Data For minimum coating thickness						Data For intermediate coating thickness						Data For maximum coating thickness						
Min. Thickness	Inter. Thickness	Max. Thickness	Min. Thickness	Inter. Thickness	Max. Thickness	Min. Thickness	Inter. Thickness	Max. Thickness	Min. Thickness	Inter. Thickness	Max. Thickness	Min. Thickness	Inter. Thickness	Max. Thickness	Min. Thickness	Inter. Thickness	Max. Thickness	
Time	Tempe.	Time	Tempe.	Time	Tempe.	Time	Tempe.	Time	Tempe.	Time	Tempe.	Time	Tempe.	Time	Tempe.	Time	Tempe.	
Minutes	°C	Minutes	°C	Minutes	°C	Minutes	°C	Minutes	°C	Minutes	°C	Minutes	°C	Minutes	°C	Minutes	°C	
1	0.1667	20.6011	0.1667	20.4214	0.1667	20.4133	0.1667	20.4983	0.1667	20.3498	0.1667	20.3429	0.1667	20.4094	0.1667	20.2875	0.1667	20.2819
2	0.3333	21.7778	0.3333	21.2317	0.3333	21.1661	0.3333	21.4843	0.3333	21.0299	0.3333	20.9751	0.3333	21.3332	0.3333	20.856	0.3333	20.8109
3	0.5	23.2781	0.5	22.4614	0.5	22.383	0.5	22.9851	0.5	22.0557	0.5	21.9065	0.5	22.4774	0.5	21.7067	0.5	21.5838
4	0.75	27.8777	0.75	25.398	0.75	24.9101	0.75	26.4846	0.75	24.4404	0.75	24.0447	0.75	25.2699	0.75	23.6166	0.75	23.285
5	1.125	37.3769	1.125	31.0486	1.125	30.6973	1.125	33.6759	1.125	29.4483	1.125	28.4503	1.125	30.8501	1.125	27.4787	1.125	26.6779
6	1.6875	52.8889	1.6875	42.8416	1.6875	40.2856	1.5141	48.003	1.5141	34.6608	1.5141	32.9833	1.5141	36.6014	1.5141	31.5299	1.5141	30.2008
7	2.53125	77.9681	2.53125	61.6353	2.53125	56.7904	1.875	48.8803	1.875	40.2886	1.875	37.9123	1.875	42.5007	1.875	35.8008	1.875	33.9364
8	3.375	103.072	3.375	81.2249	3.375	76.9888	2.375	60.4957	2.375	49.0388	2.375	45.639	2.25	48.4067	2.25	40.1711	2.25	37.7747
9	4.00782	117.302	4.21875	101.223	4.21875	96.7233	3.28125	77.467	3.28125	62.3956	3.28125	57.5876	2.8125	57.133	2.8125	46.8516	2.8125	43.6975
10	4.64063	131.724	5.48438	125.794	5.48438	120.073	4.125	93.4167	4.125	75.561	4.125	69.5328	3.65625	69.567	3.65625	56.7974	3.65625	52.6297
11	5.27343	146.505	6.24778	140.621	6.24778	134.855	4.53125	103.6663	4.53125	84.783	4.53125	78.6801	4.02188	86.4142	4.02188	71.0977	4.02188	65.6495
12	5.90623	161.097	7.0929	162.195	7.0929	165.726	5.05625	126.24	5.05625	109.714	5.05625	102.624	4.1875	101.299	4.1875	84.2487	4.1875	77.9111
13	6.53907	174.92	8.25173	177.554	8.25173	181.777	5.92188	140.191	5.92188	122.602	5.92188	120.87	4.74531	112.041	4.74531	90.8959	4.74531	84.5565
14	7.17147	185.248	9.89587	188.994	9.89587	199.701	6.1875	152.256	6.1875	134.61	6.1875	137.272	5.1875	121.356	5.1875	99.8438	5.1875	94.5948
15	7.80387	195.463	11.6202	199.282	11.6202	210.436	6.45312	162.486	6.45312	145.533	6.45312	151.457	5.69848	130.211	5.69848	106.628	5.69848	100.028
16	8.43628	205.513	13.4441	209.271	13.4441	221.877	6.72188	171.293	6.72188	155.25	6.72188	163.547	5.98438	138.175	5.98438	113.063	5.98438	106.478
17	9.06868	215.563	15.268	219.271	15.268	232.923	7.00000	180.191	7.00000	163.547	7.00000	171.999	6.26906	145.241	6.26906	120.073	6.26906	113.846
18	9.70108	225.613	17.0919	228.923	17.0919	242.975	7.27812	189.104	7.27812	171.999	7.27812	180.877	6.54781	154.241	6.54781	126.628	6.54781	120.028
19	10.33348	235.663	18.9158	238.133	18.9158	252.923	7.55625	198.017	7.55625	184.173	7.55625	194.478	6.82656	163.547	6.82656	131.846	6.82656	126.628
20	10.96588	245.713	20.7397	249.643	20.7397	262.875	7.83438	206.930	7.83438	191.041	7.83438	201.783	7.10625	172.923	7.10625	137.774	7.10625	131.846
21	11.59828	255.763	22.5636	253.573	22.5636	272.823	8.11250	215.843	8.11250	200.000	8.11250	210.935	7.37812	184.173	7.37812	143.709	7.37812	136.823
22	12.23068	265.813	24.3875	261.383	24.3875	282.773	8.39063	224.756	8.39063	209.013	8.39063	220.868	7.65000	193.041	7.65000	150.000	7.65000	141.846
23	12.86308	275.863	26.2114	274.193	26.2114	292.723	8.66875	233.669	8.66875	218.026	8.66875	229.783	7.90938	202.000	7.90938	156.146	7.90938	146.823
24	13.49548	285.913	28.0353	282.723	28.0353	302.673	8.94688	242.582	8.94688	227.039	8.94688	238.696	8.16875	211.000	8.16875	161.446	8.16875	151.846
25	14.12788	295.963	29.8592	296.553	29.8592	312.623	9.22500	251.495	9.22500	236.052	9.22500	247.609	8.42875	220.000	8.42875	166.146	8.42875	156.823
26	14.76028	306.013	31.6831	307.143	31.6831	322.573	9.50312	260.408	9.50312	244.907	9.50312	256.526	8.69688	229.000	8.69688	170.846	8.69688	161.846
27	15.39268	316.063	33.5070	317.273	33.5070	332.523	9.78125	269.321	9.78125	253.820	9.78125	265.449	8.96500	238.000	8.96500	175.646	8.96500	166.823
28	16.02508	326.113	35.3309	328.483	35.3309	342.473	10.05938	278.234	10.05938	262.733	10.05938	274.362	9.23312	247.000	9.23312	180.446	9.23312	171.846
29	16.65748	336.163	37.1548	339.853	37.1548	352.423	10.33750	287.147	10.33750	271.646	10.33750	283.285	9.50125	256.000	9.50125	185.246	9.50125	176.823
30	17.28988	346.213	38.9787	349.623	38.9787	362.373	10.61563	296.060	10.61563	280.559	10.61563	292.208	9.77938	265.000	9.77938	189.846	9.77938	181.846
31	17.92228	356.263	40.8026	359.993	40.8026	372.323	10.89375	304.973	10.89375	289.472	10.89375	301.131	10.05125	274.000	10.05125	194.446	10.05125	186.823
32	18.55468	366.313	42.6265	369.763	42.6265	382.273	11.17188	313.886	11.17188	298.385	11.17188	310.054	10.32938	283.000	10.32938	199.046	10.32938	191.846
33	19.18708	376.363	44.4504	379.533	44.4504	392.223	11.45000	322.799	11.45000	307.298	11.45000	318.967	10.60750	292.000	10.60750	203.646	10.60750	196.823
34	19.81948	386.413	46.2743	389.303	46.2743	402.173	11.72812	331.712	11.72812	316.211	11.72812	327.880	10.88563	301.000	10.88563	208.046	10.88563	201.846
35	20.45188	396.463	48.0982	399.073	48.0982	412.123	12.00625	340.625	12.00625	325.024	12.00625	336.793	11.16375	310.000	11.16375	212.446	11.16375	206.823
36	21.08428	406.513	49.9221	408.843	49.9221	422.073	12.28438	349.538	12.28438	333.937	12.28438	345.706	11.44188	319.000	11.44188	217.046	11.44188	211.846
37	21.71668	416.563	51.7460	418.613	51.7460	432.023	12.56250	358.451	12.56250	343.050	12.56250	354.619	11.72000	328.000	11.72000	221.646	11.72000	216.823
38	22.34908	426.613	53.5699	428.383	53.5699	441.973	12.84063	367.364	12.84063	352.163	12.84063	363.532	12.01812	337.000	12.01812	226.246	12.01812	221.846
39	22.98148	436.663	55.3938	438.153	55.3938	451.923	13.11875	376.277	13.11875	361.076	13.11875	372.445	12.29625	346.000	12.29625	230.846	12.29625	226.823
40	23.61388	446.713	57.2177	447.923	57.2177	461.873	13.39688	385.190	13.39688	369.989	13.39688	381.358	12.57500	355.000	12.57500	235.446	12.57500	231.846
41	24.24628	456.763	59.0416	457.693	59.0416	471.823	13.67500	394.103	13.67500	378.902	13.67500	390.271	12.85312	364.000	12.85312	240.046	12.85312	236.823
42	24.87868	466.813	60.8655	467.463	60.8655	481.773	13.95312	403.016	13.95312	387.815	13.95312	400.184	13.13125	373.000	13.13125	244.646	13.13125	241.846
43	25.51108	476.863	62.6894	477.233	62.6894	491.723	14.23125	411.929	14.23125	396.728	14.23125	409.097	13.40938	382.000	13.40938	249.246	13.40938	246.823
44	26.14348	486.913	64.5133	487.003	64.5133	501.673	14.50938	420.842	14.50938	405.641	14.50938	418.010	13.68750	391.000	13.68750	253.846	13.68750	251.846
45	26.77588	496.963	66.3372	497.773	66.3372	511.623	14.78750	429.755	14.78750	414.554	14.78750	426.923	13.96563	400.000	13.96563	258.446	13.96563	256.823
46	27.40828	507.013	68.1611	498.543	68.1611	521.573	15.06563	438.668	15.06563	423.467	15.06563	435.836	14.24375	409.000	14.24375	263.046	14.24375	261.846
47	28.04068	517.063	69.9850	499.313	69.9850	531.523	15.34375	447.581	15.34375	432.380	15.34375	444.749	14.52188	418.000	14.52188	267.646	14.52188	266.823

Steps followed to generate DFT tables

- 1) Deciding on maximum and minimum coating thickness
- 2) Calculating steel mean temperature in line with BS EN 13381-8:2013/Clause 3.1.12
- 3) Calculating correction factors
- 4) Correcting times using the correction factor calculated in step 3
- 5) Using the corrected time-temperature curves to generate Table 1 (Times to reach different assessment temperatures in minutes for all tests) in accordance with BS EN 13381-6:2012/Annex A
- 6) Creating Table 2 (Calculated protection thickness(mm) for a known assessment temperature and for a known fire resistance period)
- 7) Creating DFT table for various wall thicknesses (in accordance with BS EN 13381-6:2012/Annex A)

DFT table for CHS 219.1- (First Product)



Fire Performance Period - 75 minutes								
Thickness	Coating thickness in μm							
(mm)	350°C	400°C	450°C	500°C	550°C	600°C	650°C	700°C
6.3	1538	1365	1223	1075	1050	1050	1050	1050
8	1860	1626	1398	1194	1050	1050	1050	1050
10	2239	1933	1605	1333	1050	1050	1050	1050
12.5	2712	2317	1863	1508	1050	1050	1050	1050
14.2	3035	2578	2039	1626	1050	1050	1050	1050
16	3376	2855	2225	1752	1050	1050	1050	1050

Specimens after test-(First material)

T4- DFT 0.74 T5- DFT 2.9 T6- DFT 1.871 T14- DFT 1.544 T15- DFT 0.56



T16- DFT 2.713 T10- DFT 1.00 T11- DFT 3.285 T12- DFT 1.098 T13- DFT 1.098



Specimens after test-(Second material)

S4-DFT1.127

S5-DFT 0.24

S6-DFT 2.04

S14-DFT 0.18

S15-DFT 1.040



S16-DFT 2.026

S10-DFT 0.248

S11-DFT 2.028

S12-DFT 0.2

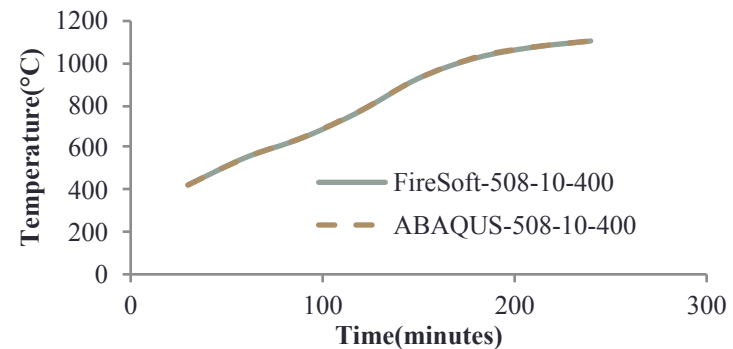
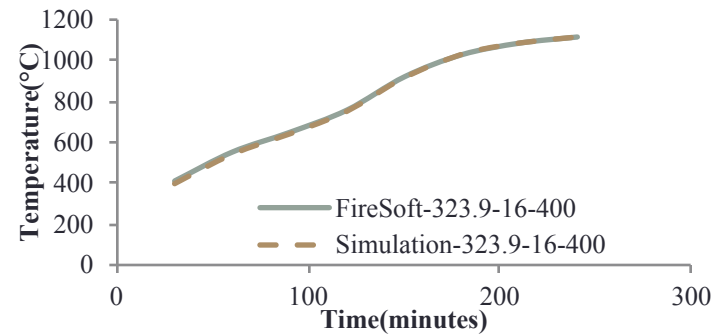
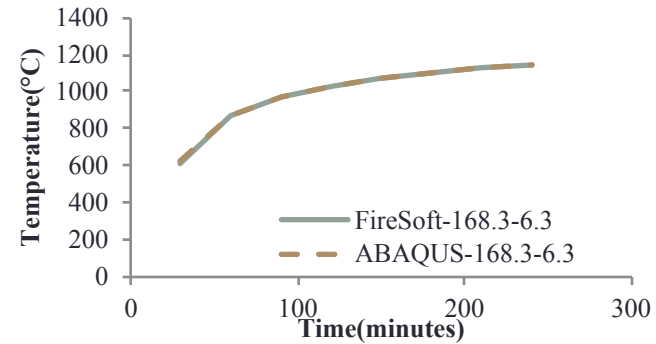
S13-DFT 2.037



Fire Soft validation against ABAQUS

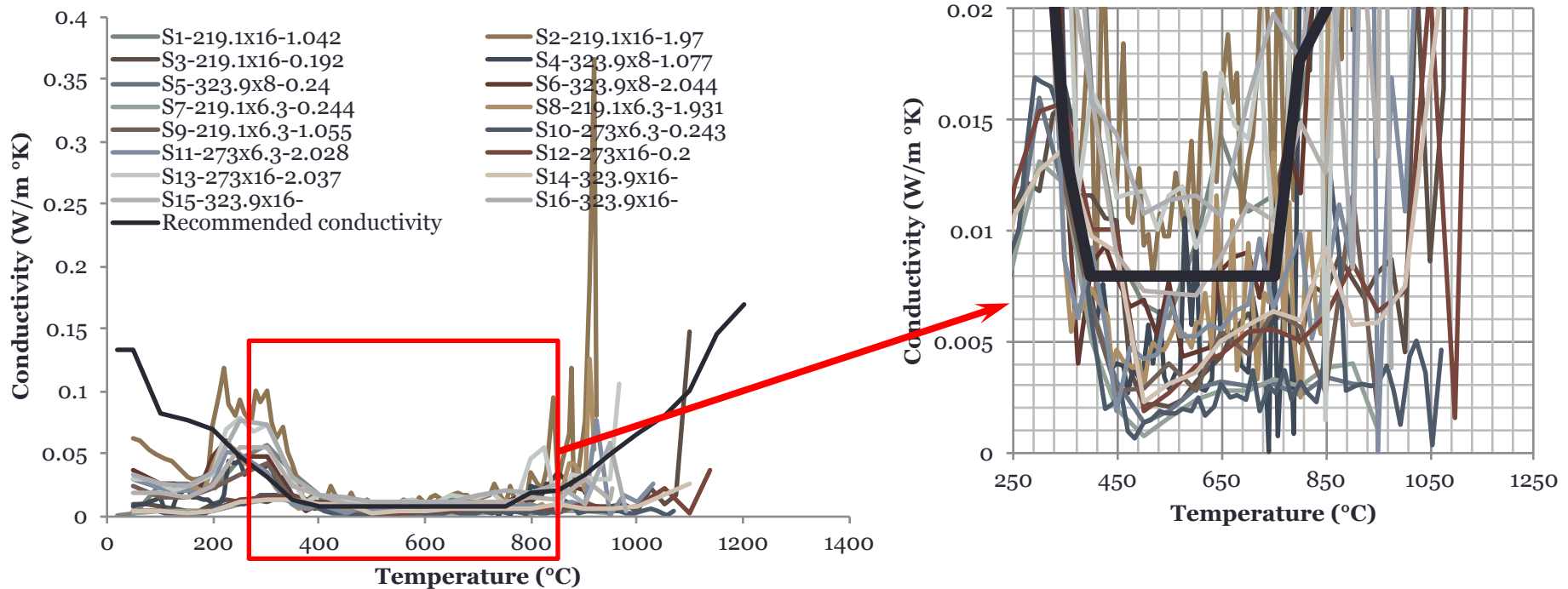
Details of simulated models

Tube diameter(m)	Wall thickness(mm)	Coating DFT(μm)	Number of elements
168.3	6.3	-	7200
219.1	6.3	-	11200
219.1	16	-	11200
273	6.3	-	18000
273	16	-	18000
323.9	6.3	-	26400
323.9	16	-	26400
508	10	-	57500
168.3	6.3	650	9400
168.3	12.5	650	7200
219.1	6.3	500	14000
219.1	16	500	12800
273	6.3	500	21500
273	16	500	21500
323.9	6.3	400	29000
323.9	16	400	29100
168.3	6.3	2444	9400
168.3	12.5	2444	7200
219.1	6.3	4500	14000
219.1	16	4500	12800
273	6.3	4500	21500
273	16	4500	21500
323.9	6.3	2400	29000
323.9	16	2400	29100
508	10	400	65300



Effective Thermal conductivity-

- 1) Calculating thermal conductivities in accordance with EN 13381-8:2013 Annex E
- 2) Effective thermal conductivity suggested in the way that could satisfy the acceptability criteria in EN 13381-8:2013-Clause 13.5



Comparison between predicted and recorded results (CHS219.1)

Table 7-1 Comparison between predicted and measured times (for CHS 219.1) for specific temperature (in Minutes)

Temp.(°C)	FS-S1	S1	Diff.-S1	FS-S2	S2	Diff.-S2	FS-S3	S3	Diff.-S3	FS-S7	S7	Diff.-S7	FS-S8	S8	Diff.-S8	FS-S9	S9	Diff.-S9
350	48.7	58.5	-20.1	68.4	74.8	-9.3	21.5	28.2	-31.4	18.9	27.5	-45.2	61.2	68.5	-11.9	42.5	56.8	-33.6
400	60.9	68.4	-12.2	83.2	87.3	-4.9	28.2	34.7	-23.0	26.4	32.7	-23.8	74.0	81.4	-10.0	54.6	66.4	-21.7
450	71.1	80.0	-12.5	97.1	99.8	-2.8	34.5	40.5	-17.2	33.0	38.5	-16.6	86.8	93.6	-7.8	64.8	76.9	-18.7
500	81.2	91.6	-12.8	110.3	113.3	-2.7	40.7	46.3	-13.7	38.9	44.4	-14.2	98.7	105.9	-7.3	73.5	85.2	-15.9
520	85.3	96.3	-12.9	115.6	118.4	-2.4	43.2	48.7	-12.7	41.2	47.0	-14.0	103.3	110.5	-6.9	77.0	89.5	-16.2
550	91.5	103.1	-12.7	123.6	125.6	-1.6	46.9	52.6	-12.1	44.7	50.9	-13.8	110.3	118.4	-7.3	82.2	98.1	-19.3
600	102.2	115.0	-12.4	137.2	136.5	0.5	53.1	59.2	-11.4	50.5	57.8	-14.4	122.1	132.8	-8.8	91.2	111.5	-22.2
650	113.0	124.0	-9.7	151.0	153.5	-1.7	59.3	66.7	-12.4	56.3	65.6	-16.5	134.9	150.0	-11.2	102.1	125.8	-23.2
700	126.4	133.5	-5.7	168.6	167.4	0.7	67.3	75.2	-11.7	62.7	75.2	-20.0	147.7	167.4	-13.3	113.0	140.6	-24.4
Difference %			-12.16			-2.663			-16.19			-19.85			-9.39			-21.71

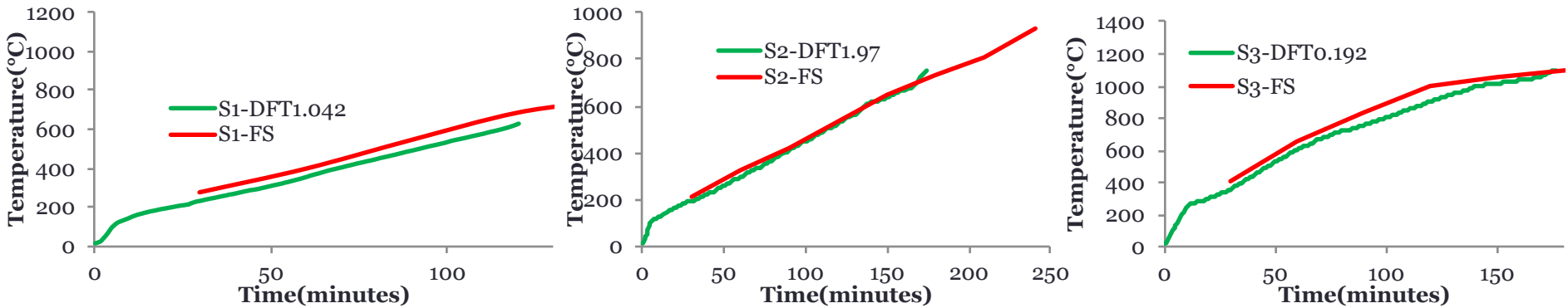
FS= FireSoft

BS EN 1338-8:2013 clause 13.5 limitations:

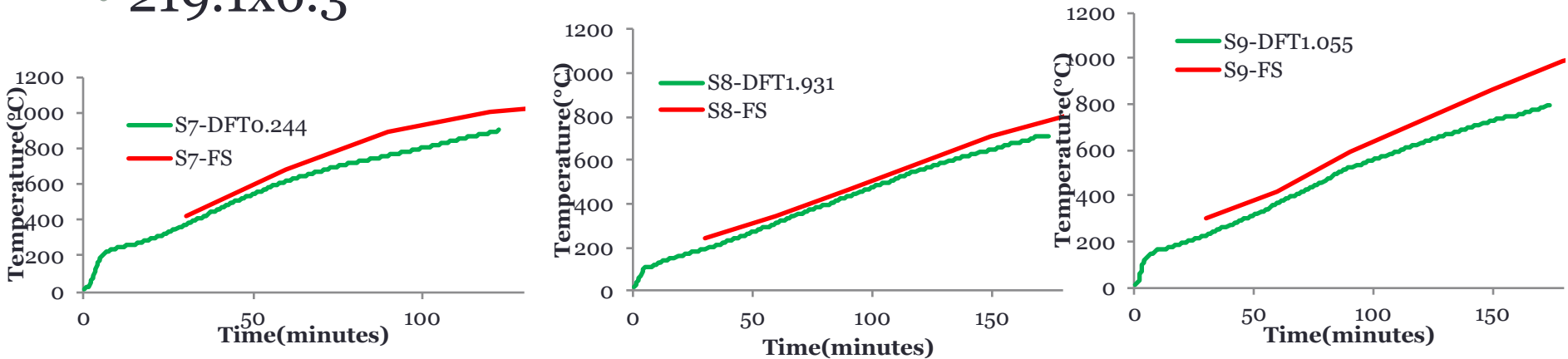
- a) For each short section, the predicted time in minutes to reach the design temperature calculated to one decimal place shall not exceed the corrected time by more than 15 %.
- b) The mean value of all percentage differences as calculated in a) shall be less than zero.
- c) A maximum of 30 % of individual values of all percentage differences as calculated in a) shall be more than zero.
- d) The results of the analysis which satisfy a) to c) above shall also comply with the following rules provided all other parameters remain constant:
 - 1) the thickness of fire protection material increases with fire resistance time;
 - 2) as the section factor increases the fire resistance time decreases;
 - 3) as fire resistance time increases the temperature increases;
 - 4) as thickness increases temperature decreases;
 - 5) as section factor increases the temperature increases;
 - 6) as section factor increases thickness increases.

Comparison between predicted and recorded results (CHS219.1)

• 219.1x16



• 219.1x6.3



Consistency check of the evaluated thermal conductivity with final DFT tables-(First material)

CHS 219.1	60 minutes of Fire resistance				90 minutes of Fire resistance			
Thickness(mm)	DFT	Expected	Calculate	Diff(%)	DFT	Expected	Calculate	Diff(%)
8	714	550 °C	547.49	0.46	1417	550 °C	572.79	-3.98
10	686	550 °C	544.32	1.04	1338	550 °C	574.08	-4.19
12.5	650	550 °C	541.77	1.52	1238	550 °C	577.79	-4.81
14.2	626	550 °C	540.62	1.73	1170	550 °C	590.99	-6.94

CHS 323.9	60 minutes of Fire resistance				120 minutes of Fire resistance			
Thickness(mm)	Level1 DFT	Expected	Calculate	Diff(%)	Level1 DFT	Expected	Calculate	Diff(%)
8	700	550 °C	519.8	-5.8	1589	550 °C	599.5	8.3
10	700	550 °C	511.3	-7.6	1526	550 °C	598.0	8.0
12.5	700	550 °C	501.5	-9.7	1447	550 °C	597.7	8.0
14.2	700	550 °C	495.2	-11.1	1393	550 °C	598.3	8.1

Accuracy of the available formulations

M. Edwards method for concrete filled hollow section

$$\frac{H_p}{A_{eff}} = \frac{1000}{t_{se}} = \frac{1000}{t_{se} + t_{ce}}$$

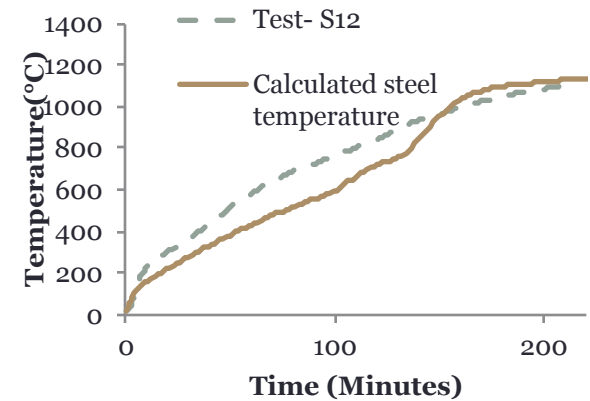
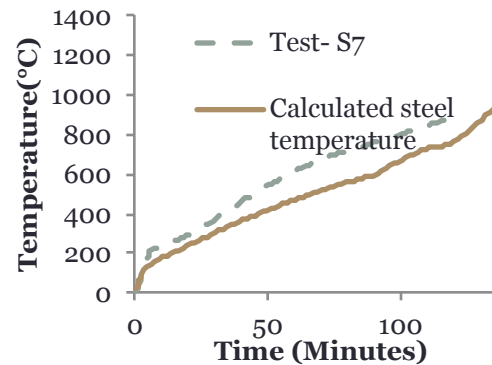
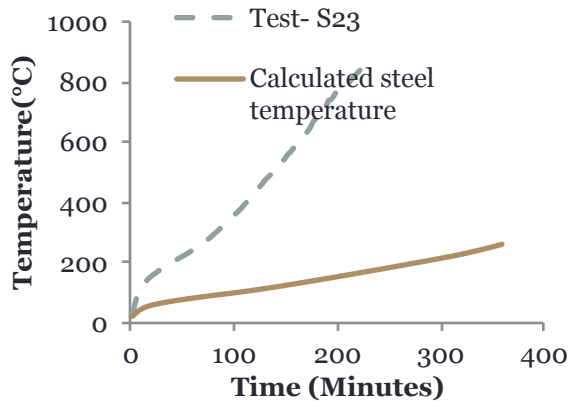
t_{ce}

$0.15b_i$

$1.8\sqrt{t_{FR}}$

$b_i < 12\sqrt{t_{FR}}$

$b_i \geq 12\sqrt{t_{FR}}$



- Thank you for your attention.

EXOVA
Warringtonfire

