Heat transfer analysis of rectangular concrete-filled steel sections

Dr Rwayda Al-Hamd, MIStructE, CEng, FHEA
Dame Kathleen Ollerenshaw Fellow in Structural Engineering
Department of Civil Engineering and Management
School of Engineering, Faculty of Science and Engineering, The University of Manchester
Email: rwayda.alhamd@manchester.ac.uk

Research gap and study aim

Why this was needed

- Fire performance of circular sections is better documented than square or rectangular sections.
- Design needs clearer understanding of heat transfer, thermal gradients and interface behaviour under different exposure conditions.

Gap: fewer detailed investigations of rectangular / square CFST heat-transfer behaviour in fire.

What the work set out to do

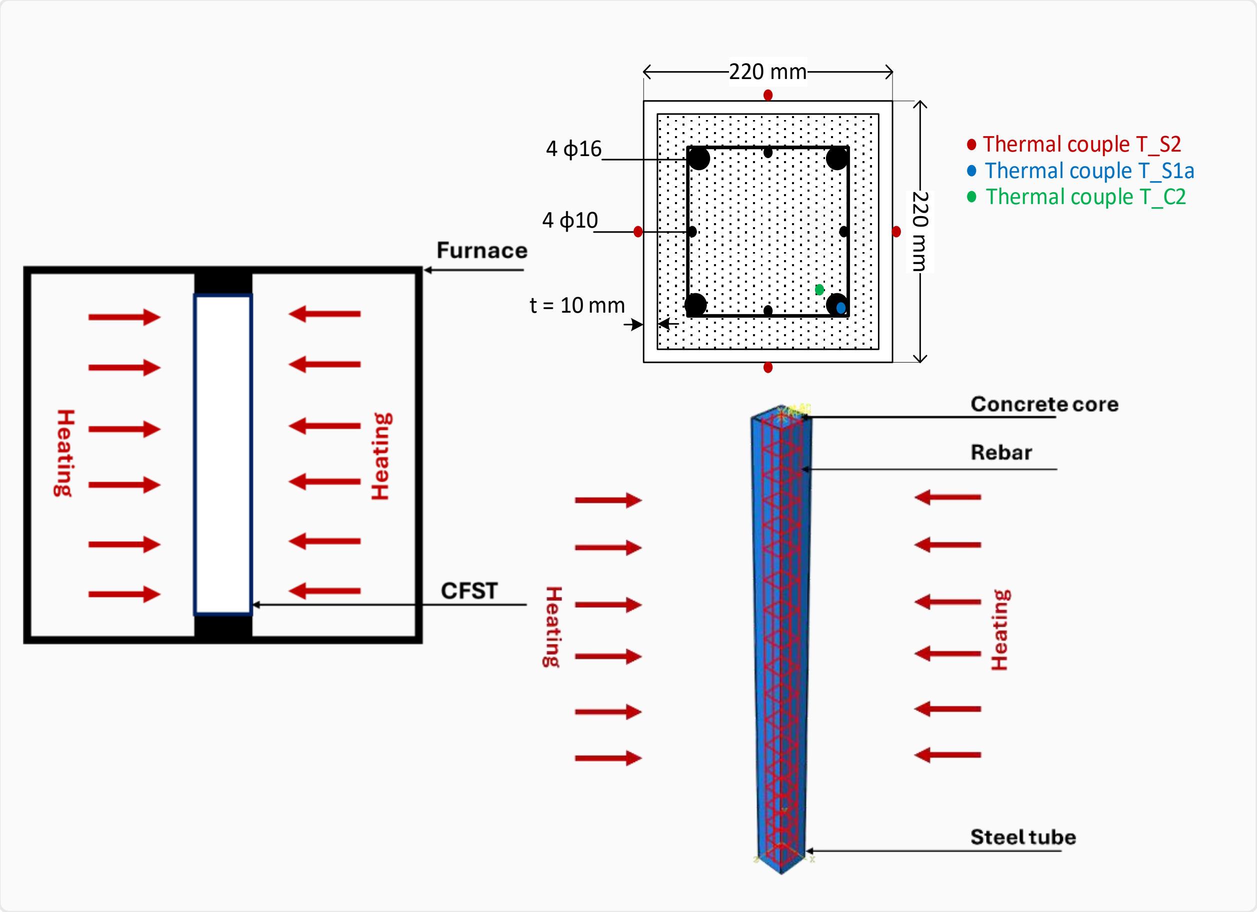
- Build a validated ABAQUS heat-transfer model for a fire-exposed CFST specimen.
- Compare solid and shell thermal modelling approaches and assess mesh sensitivity.
- Use the validated model to quantify how duration, thickness, aspect ratio, section size and heating configuration alter temperatures and heat flux.

Core message: the study is about heat-transfer characterisation first, before mechanical failure modelling.

Experimental basis for validation

Validated specimen: SC220-30ka

- Square CFST column: 220 mm × 220 mm cross-section, 3150 mm total length, 10 mm steel tube thickness.
- Standard-fire furnace test with thermocouples embedded at the surface, near-surface and deeper within the concrete core.
- This test provides the temperature histories used to validate the numerical heat-transfer model.



Experimental & numerical setup

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How the thermal model was built

1. Furnace temperature history
2. Apply convection, radiation and interface conductance
3. Assign Eurocode temperature-dependent thermal properties
4. Compare model output with measured temperatures

Key modelling inputs

- Convection coefficient: 0.08 W/m²K; emissivity: 0.7; thermal contact conductance at steel–concrete interface: 0.5.
- Transient heat transfer: mechanical supports and restraint effects were intentionally excluded at this stage.
- The model therefore isolates temperature distribution and heat flux before moving to any thermo-mechanical coupling.

Model choices: materials, element type and mesh

Thermal material model

- Steel and concrete properties were defined as temperature-dependent functions following Eurocode provisions.

- This captures thermal degradation rather than keeping conductivity or heat capacity constant through heating.

- The approach is suited to realistic fire-driven gradients within composite sections.

Element comparison

DC3D8
solid elements

DS4
shell elements

Solid elements were taken forward because they represent 3D thermal gradients more faithfully.

Mesh choice

- 10, 15 and 20 mm meshes all followed the measured trend reasonably well.

- Differences were small, but 10 mm gave slightly better agreement where gradients were sharper.

- The final study therefore used a 10 mm mesh as the best balance between accuracy and computational time.

Selected model: solid elements + 10 mm mesh

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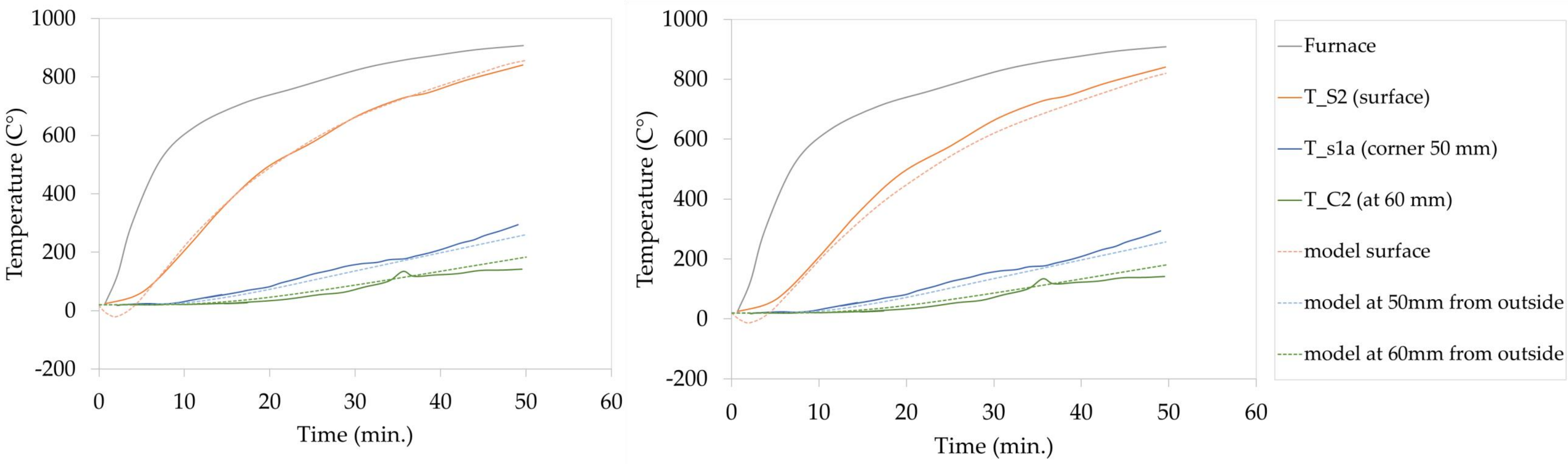
Validation: measured and predicted temperatures



(a) solid element and

(b) shell element

Key point: the solid model tracked the experimental heating curve well and was preferred for the parametric study.

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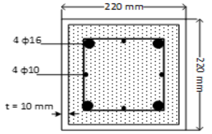
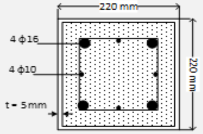
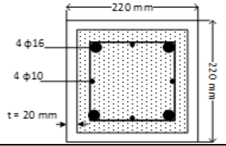
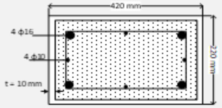
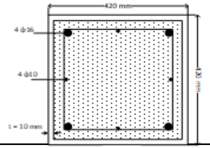
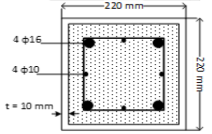
Parametric study programme

Table 1. Investigation Plan.

Case #	Section Dimensions (mm)	Thickness (mm)	Heating Time (hour)	Measured Temperature Location
Case 1	 220x220	10	1, 2 and 3	At the Surface. At 50mm from the Centre. At the Centre.
Case 2	 220x220	5	1, 2 and 3	At the Surface. At 50mm from the Centre. At the Centre.
Case 3	 220x220	20	1, 2 and 3	At the Surface. At 50mm from the Centre. At the Centre.
Case 4	 220x420	10	1, 2 and 3	At the Surface. At 50mm from the Centre. At the Centre.
Case 5	 420x420	10	1, 2 and 3	At the Surface. At 50mm from the Centre. At the Centre.
Case 6	 220x220	10	1, 2 and 3	Heating from two-sides

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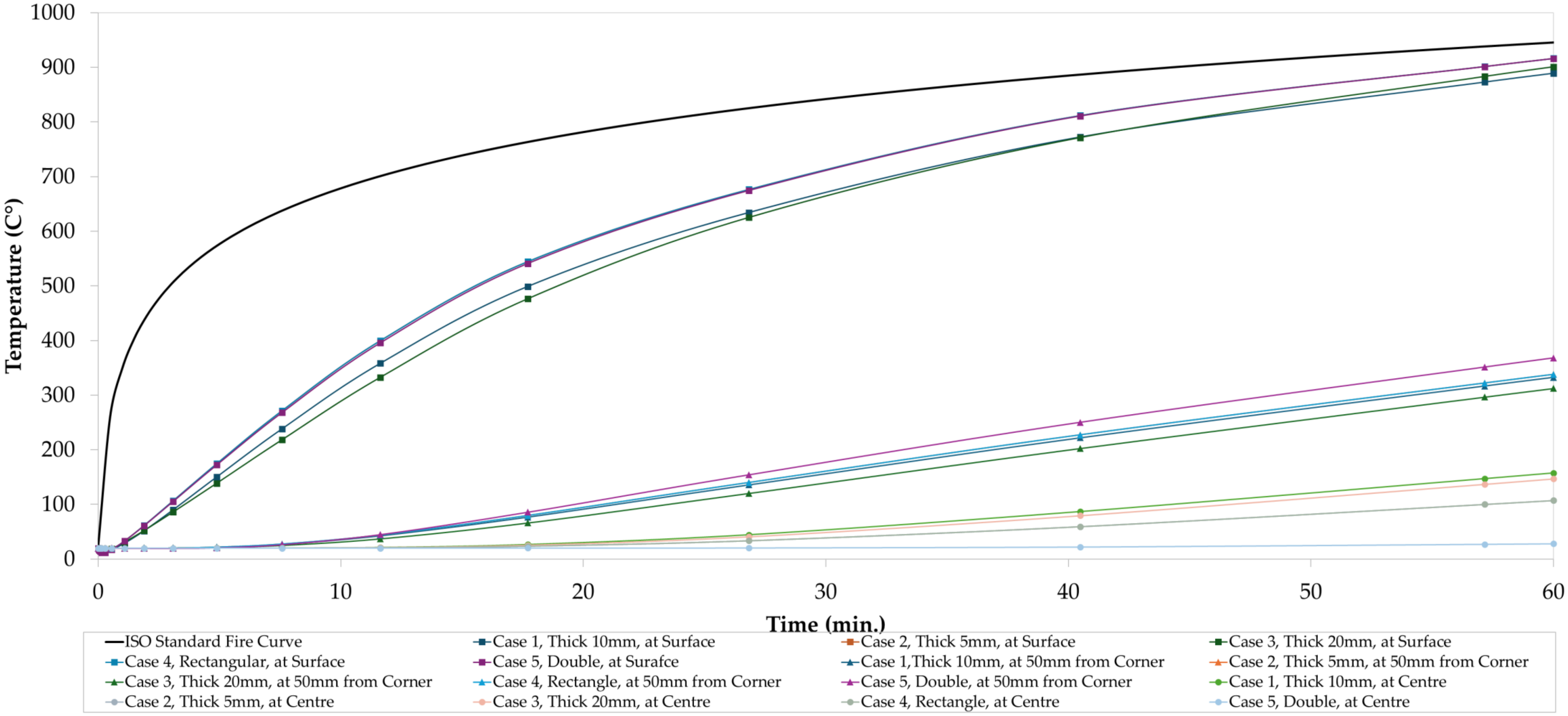
1 hour



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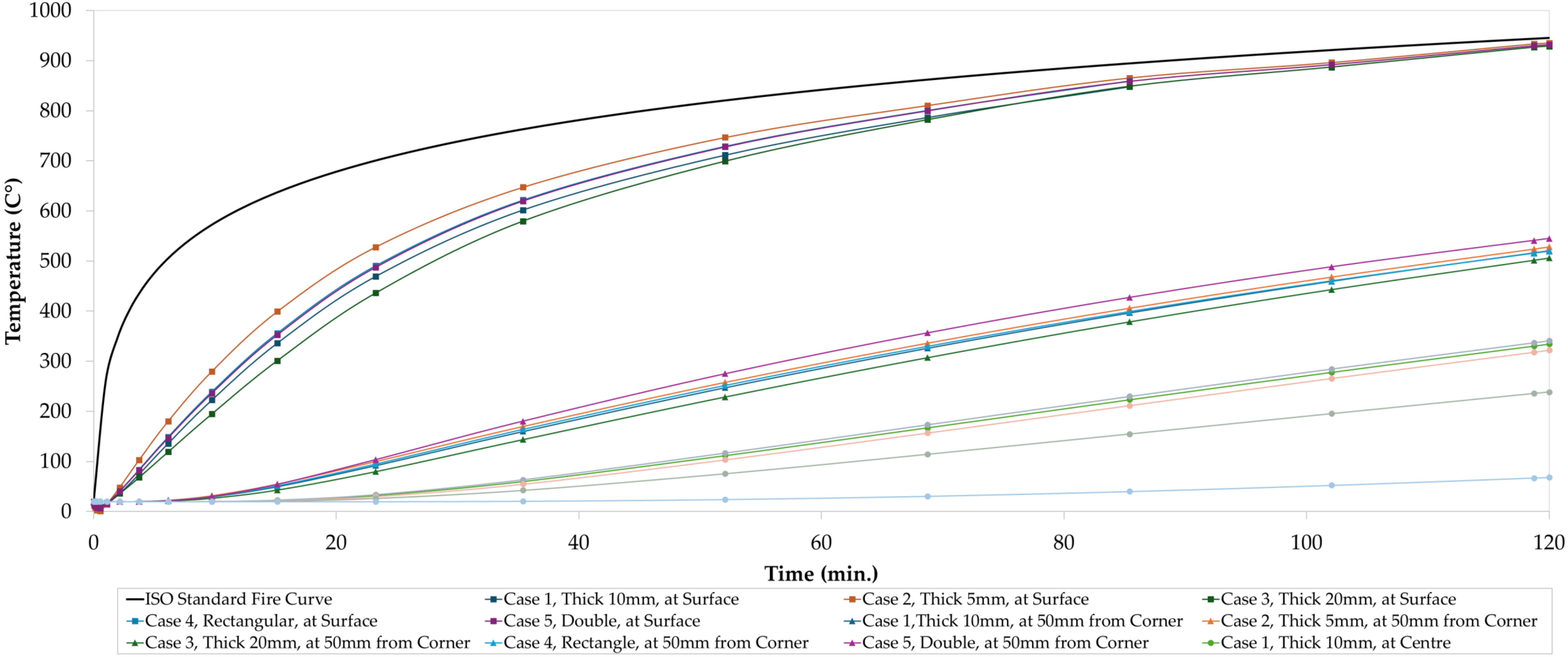
2 hour



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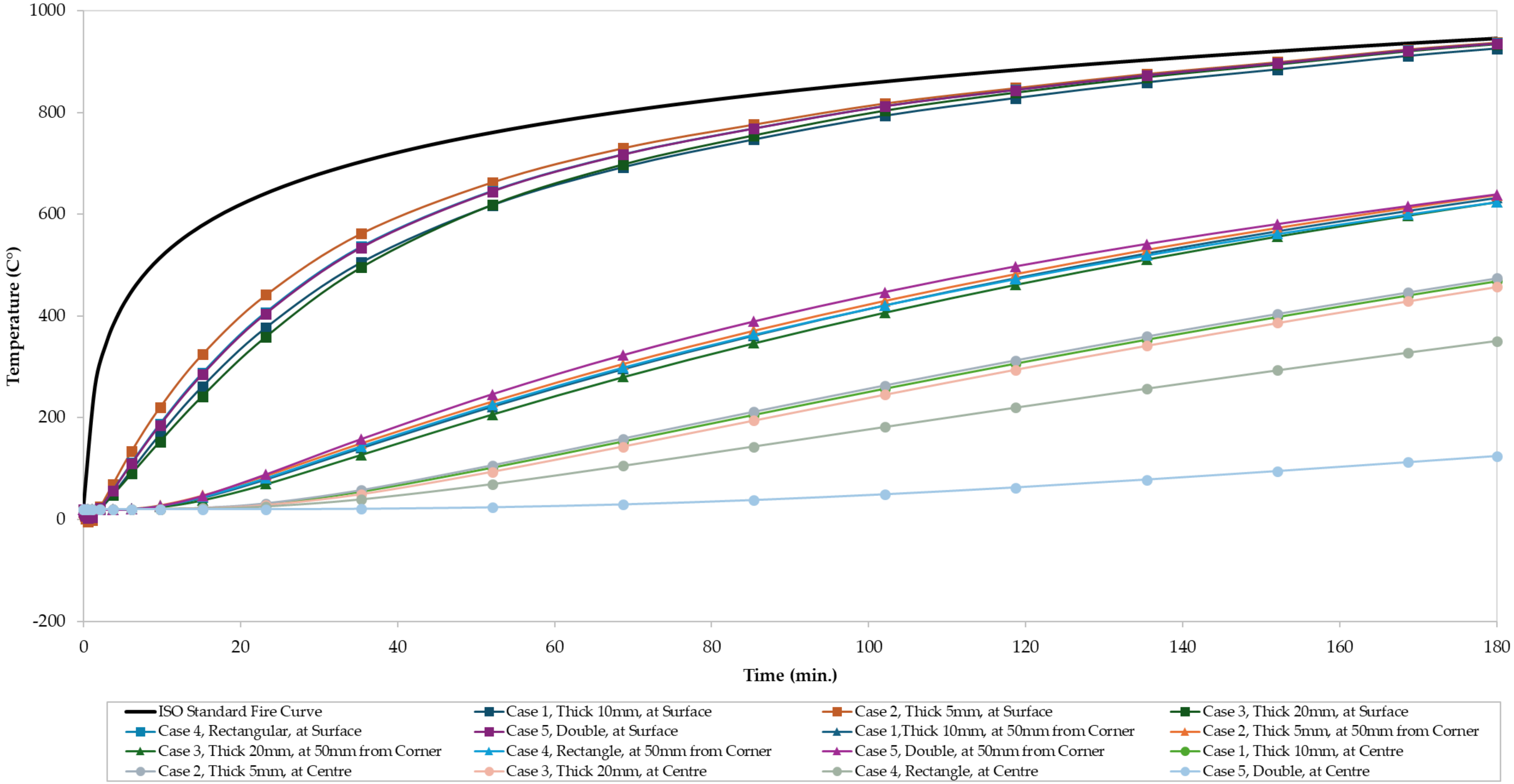
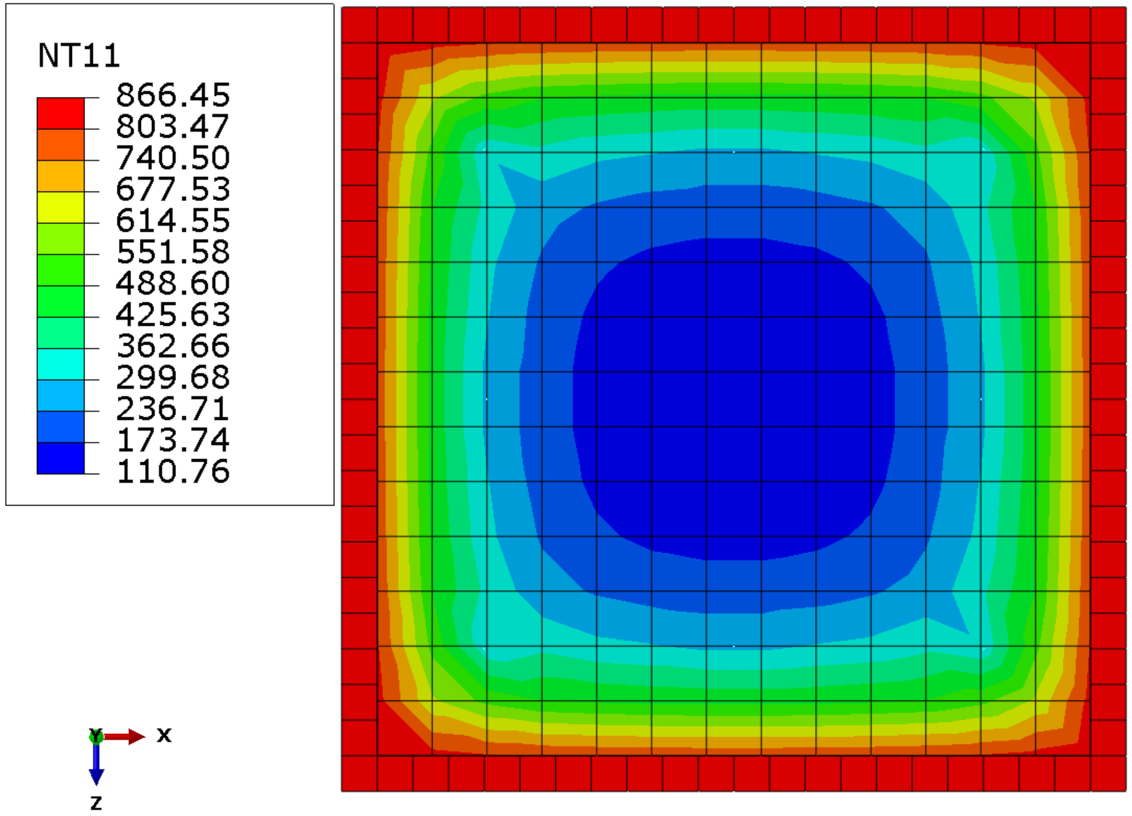
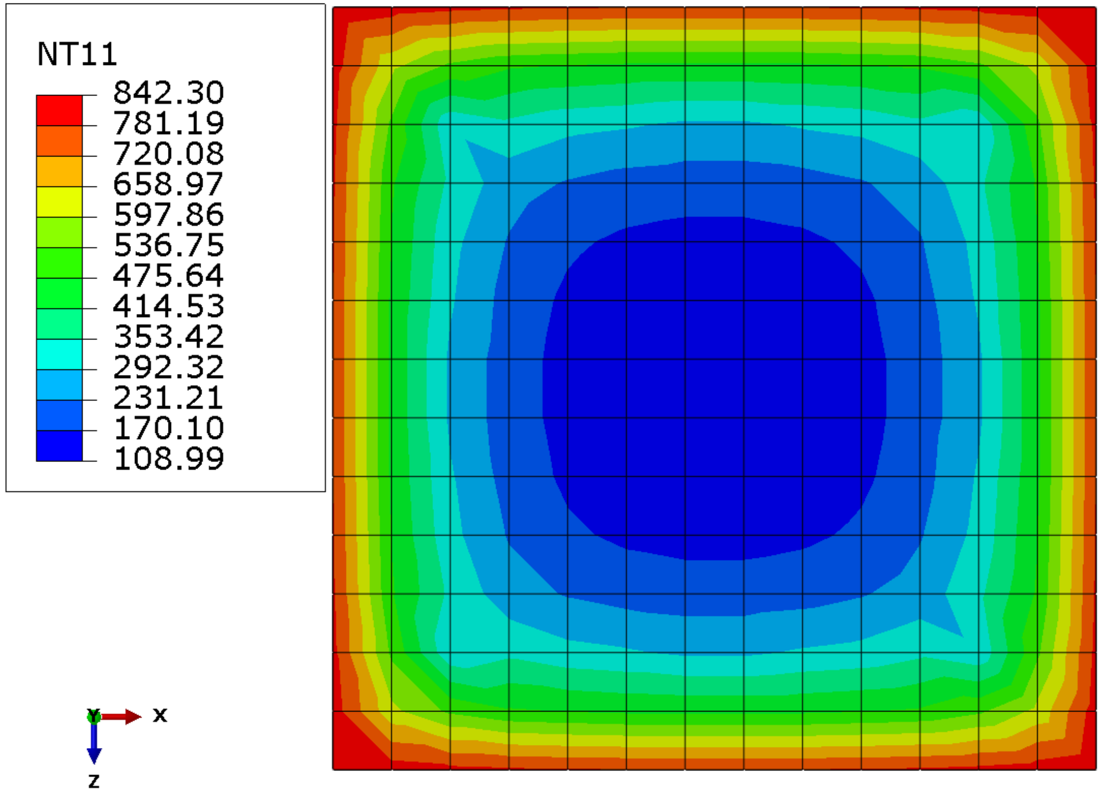
3 hour


1000
800
600
400
200
0
-200
Temperature (C°)
0
20
40
60
80
100
120
140
160
180
Time (min.)
ISO Standard Fire Curve
Case 1, Thick 10mm, at Surface
Case 2, Thick 5mm, at Surface
Case 3, Thick 20mm, at Surface
Case 4, Rectangular, at Surface
Case 5, Double, at Surface
Case 1,Thick 10mm, at 50mm from Corner
Case 2, Thick 5mm, at 50mm from Corner
Case 3, Thick 20mm, at 50mm from Corner
Case 4, Rectangle, at 50mm from Corner
Case 5, Double, at 50mm from Corner
Case 1, Thick 10mm, at Centre
Case 2, Thick 5mm, at Centre
Case 3, Thick 20mm, at Centre
Case 4, Rectangle, at Centre
Case 5, Double, at Centre

Key finding 1 Solid element gives better understanding





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Key finding 2: The steel thickness had minimal effects on core concrete temperatures and steel rebar behaviour.

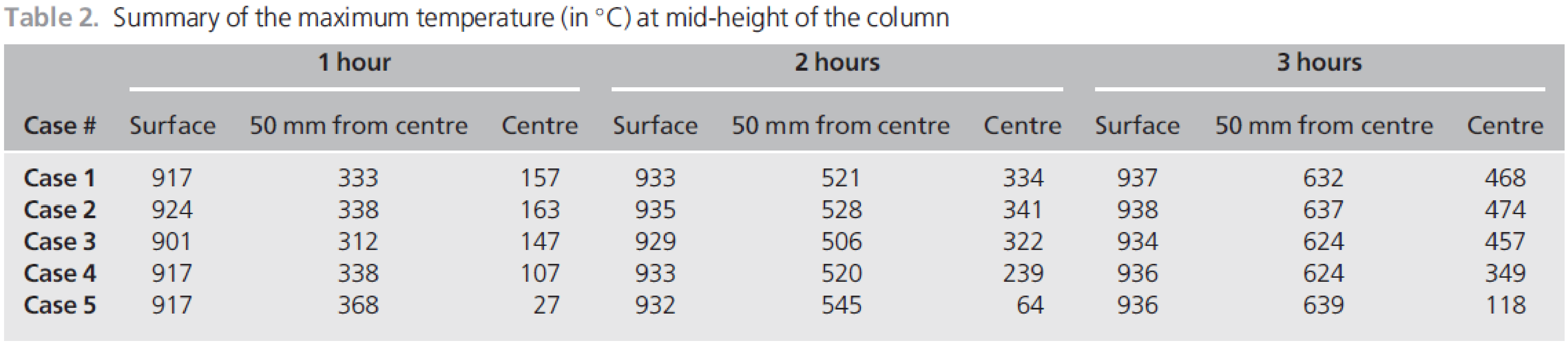

Table 2. Summary of the maximum temperature (in °C) at mid-height of the column

	1 hour			2 hours			3 hours		
Case #	Surface	50 mm from centre	Centre	Surface	50 mm from centre	Centre	Surface	50 mm from centre	Centre
Case 1	917	333	157	933	521	334	937	632	468
Case 2	924	338	163	935	528	341	938	637	474
Case 3	901	312	147	929	506	322	934	624	457
Case 4	917	338	107	933	520	239	936	624	349
Case 5	917	368	27	932	545	64	936	639	118

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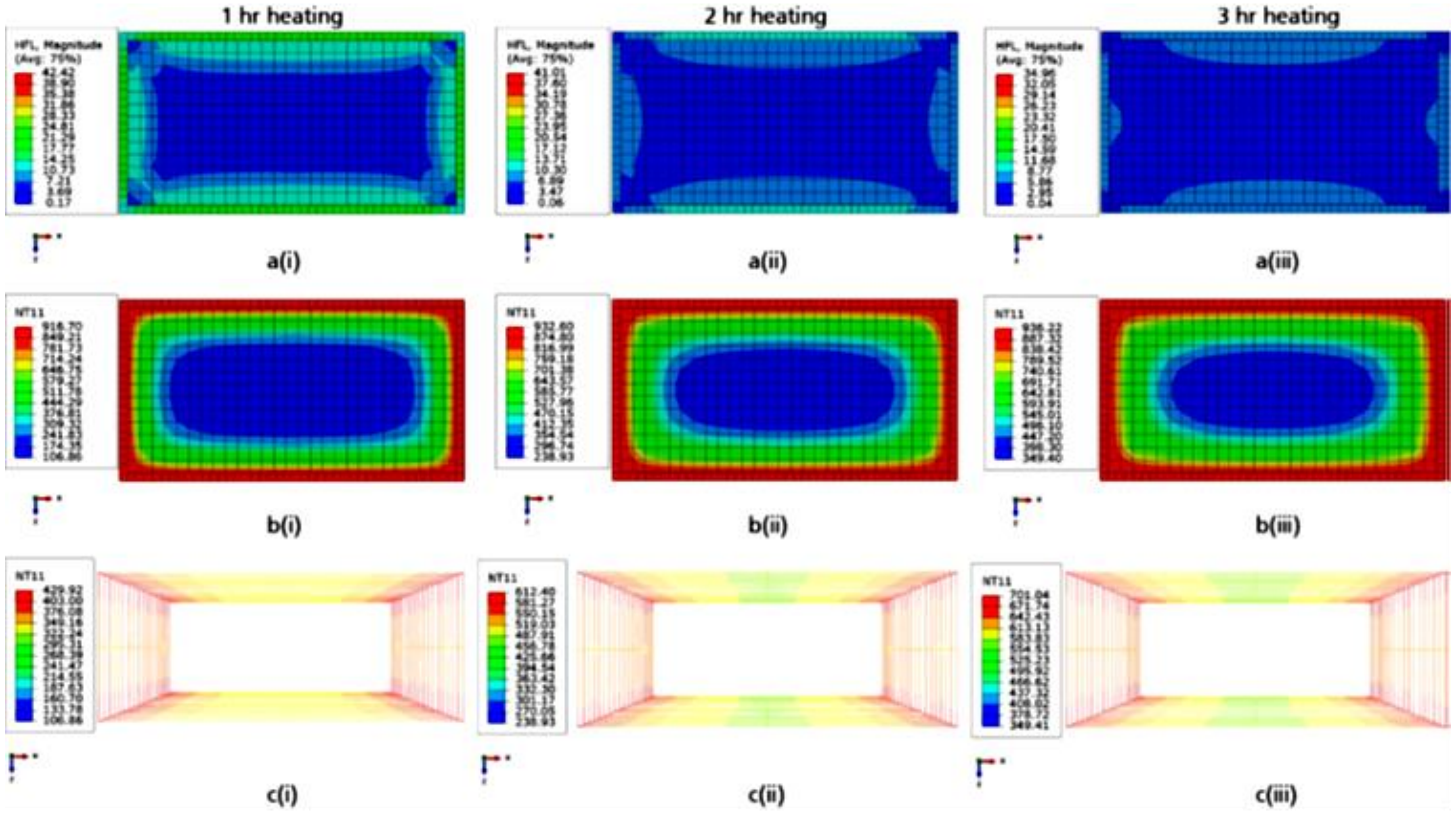
Key finding 3:The aspect ratio adjustments showed consistent trends in the HFL changes, highlighting the importance of balanced heating distribution across section dimensions.



The node temperature (NT) distribution for Case 4 where a(i), a(ii), a(iii) heat flux (HFL), b(i), b(ii), b(iii) NT at cross-section, and c(i), c(ii), c(iii) NT for rebar

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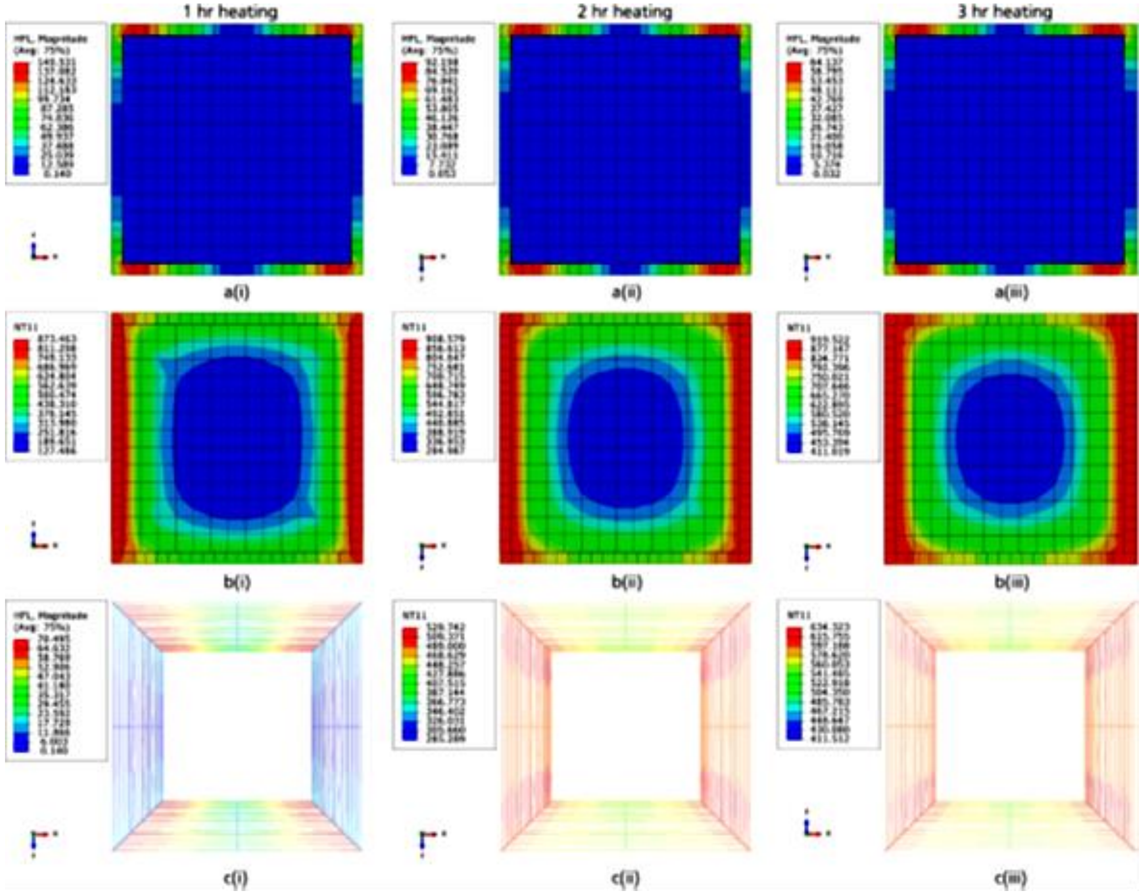
Key finding 4:Although heating the opposite sides of the column has impacted the steel temperature, this configuration results in a more symmetrical heat distribution within the concrete.



The node temperature (NT) distribution for Case 6 where a(i), a(ii), a(iii) heat flux (HFL), b(i), b(ii), b(iii) NT at cross-section, and c(i), c(ii), c(iii) NT for rebar

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Limitations and next step

- The analysis is thermal only: no structural deformation, plasticity, creep or failure was modelled.
- The study focuses on temperature fields, heat flux and thermal gradients rather than residual capacity or collapse.
- So, the results should be read as a validated thermal platform, not a complete structural-fire model.

The paper establishes the thermal platform; the next paper can address structural response.

Three points to leave with

1. The validated solid-element model reproduced the measured thermal response well enough to support a broader parametric study.
2. Section size and exposure direction dominate the thermal story more than simple increases in steel wall thickness.
3. The work provides a credible base for future coupled thermo-mechanical modelling of CFSTs in fire.

Thank you

Find me on linkedin

Rwayda Al Hamd
PhD, MSc, BSc, FHEA

My Research Website:
https://dralhamd.co.uk/

Rwayda.alhamd@manchester.ac.uk

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