University of Sheffield

Contaminated Concrete Removal Using Controlled Heat–Induced Spalling

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EPSRC Engineering and Physical Sciences Research Council

NATIONAL NUCLEAR LABORATORY

Sellafield Ltd

Dounreay Site Restoration Ltd

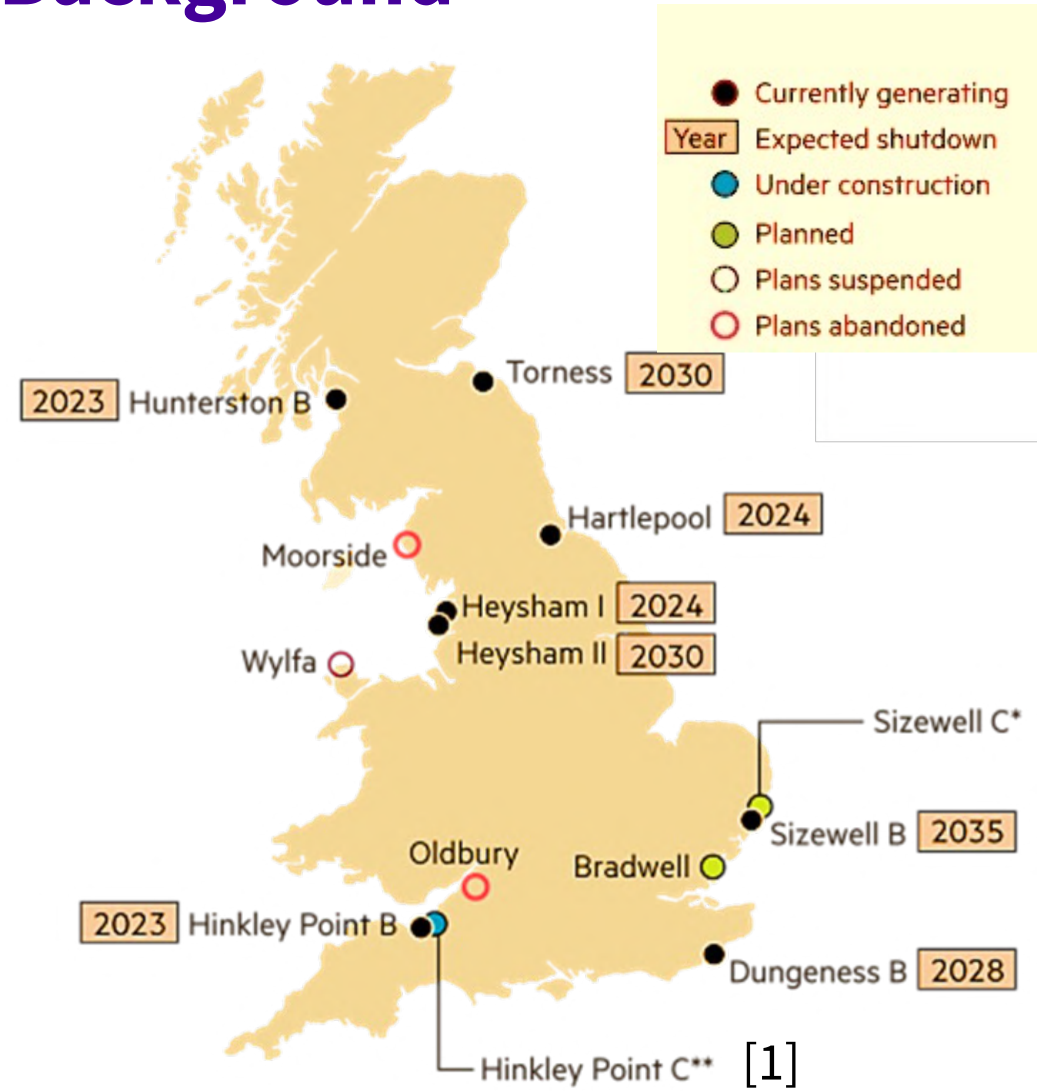
[redacted]

Scope of the Project – Background

Background

Development of a contaminated concrete removal technique using heat-induced spalling to decommission nuclear power stations

- Current annual cost of decommissioning: £ 3 billion [2]
- Most currently operational nuclear power stations to shut down by 2030
- 17 nuclear power stations already in the process of decommissioning [3]



[1]

Scope of the Project – Research Aims

Project Aim

Improve understanding on the mechanisms of heat-induced concrete spalling by developing accurate numerical models and evaluating their uncertainty

What is heat-induced spalling?

Spalling is the phenomenon where concrete pieces detach from its surface, accompanied with an energy release due to exposure to rapid heating conditions.

Channel tunnel fire 1996

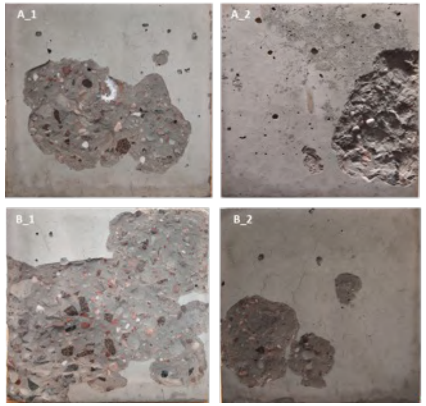
Mont-Blanc tunnel fire 1999

Great belt tunnel fire 1994

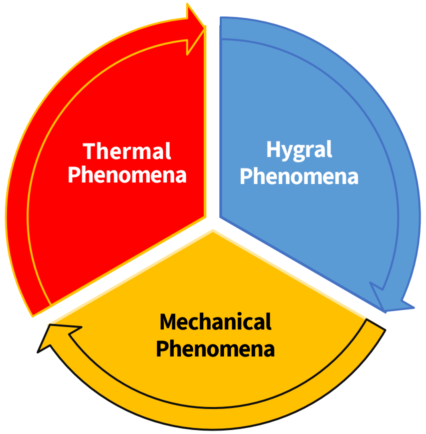
Scope of the Project – Problem Statement

Why can we not predict spalling?

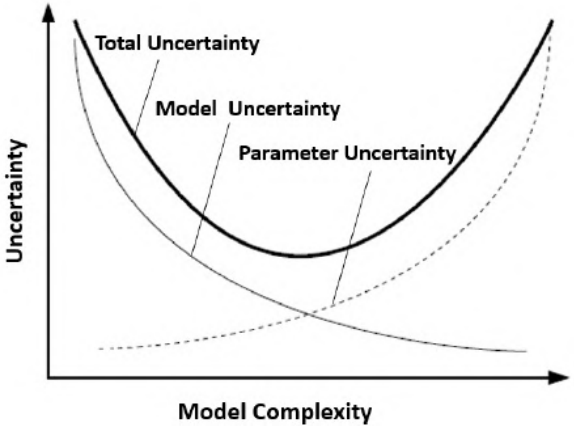
- Variability of concrete



- Multiphysics phenomena occurring simultaneously



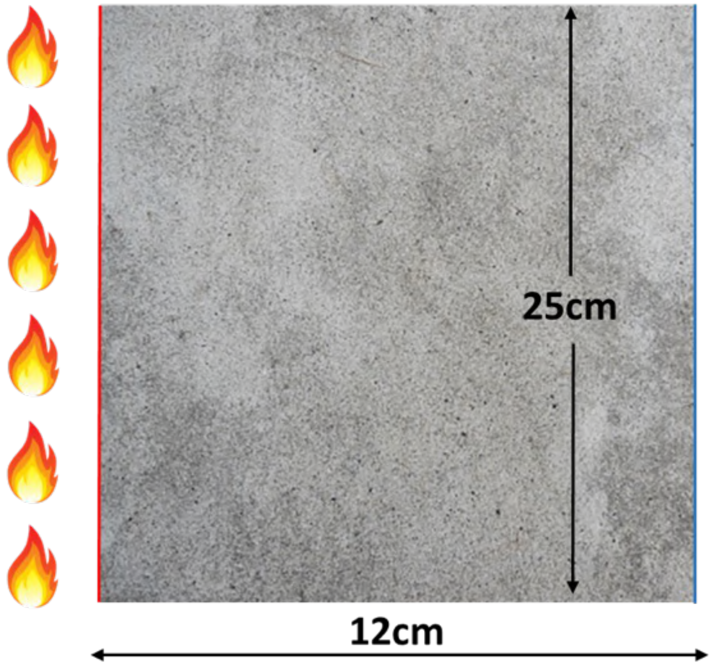
- Increased modelling uncertainty due to model complexity

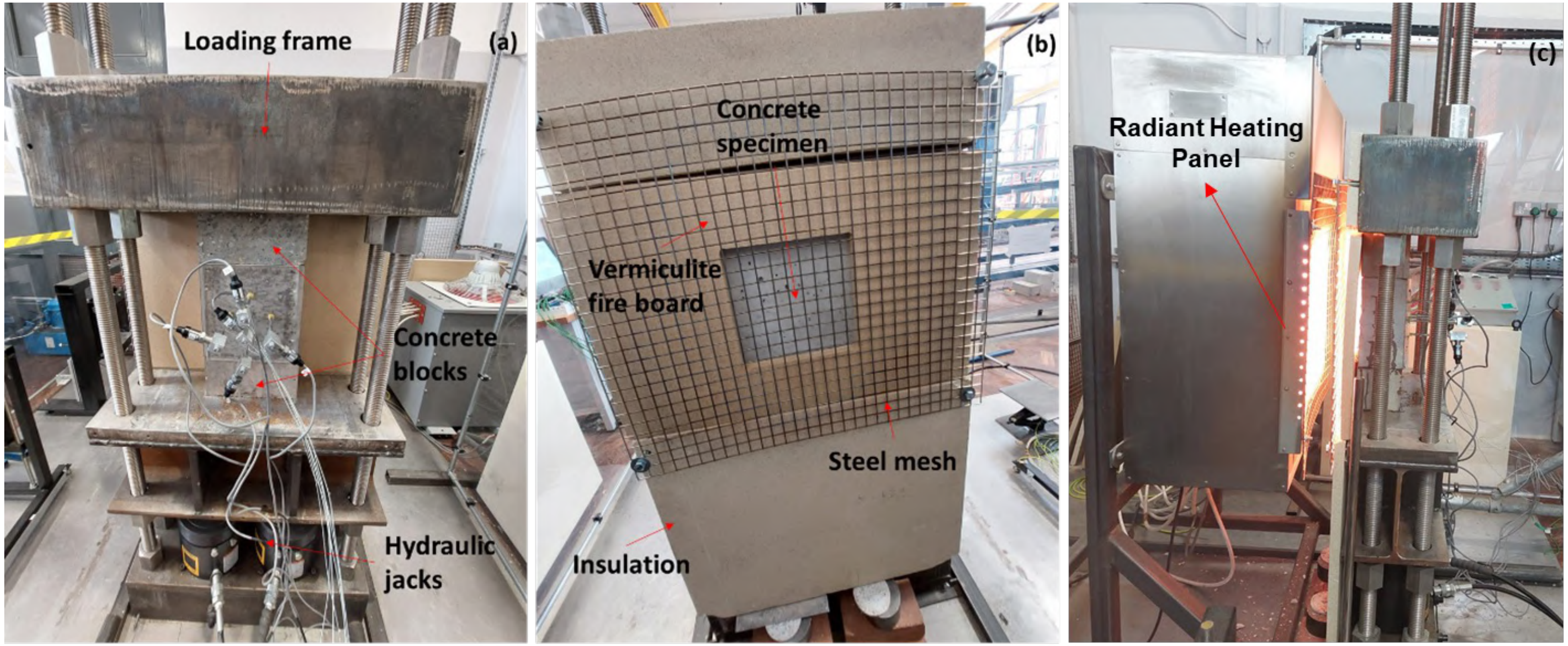


Phenomena in Heated Concrete

Thermal	Hygral	Mechanical
Heat Transfer	Mass Transport	Mechanical Aspect
		
Energy Balance	Mass Balance	Momentum Balance
⇩	⇩	⇩
Temperature Profiles	Pressure Profiles	Cracking

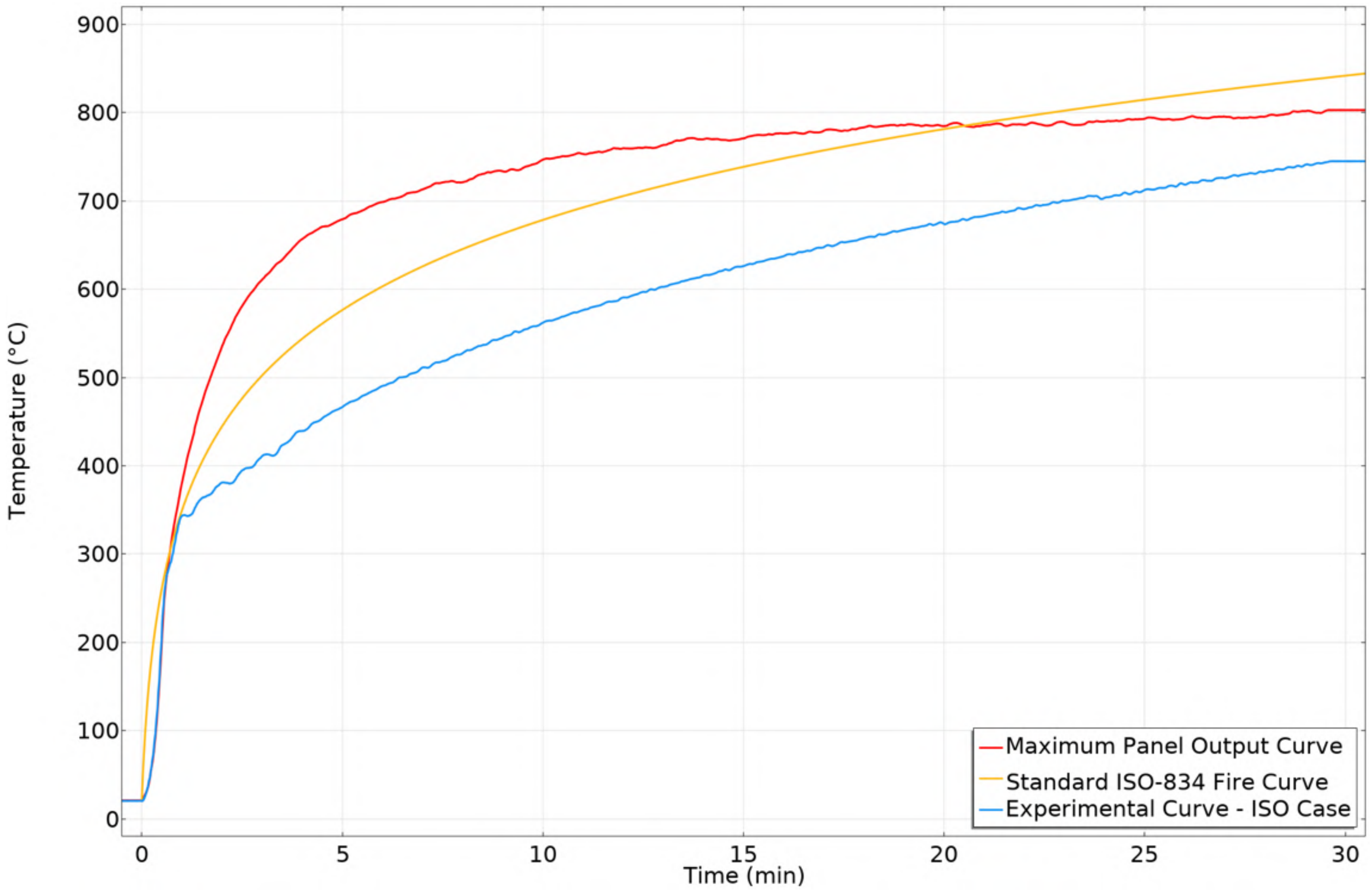
Experimental Work – Overview of Test Setup



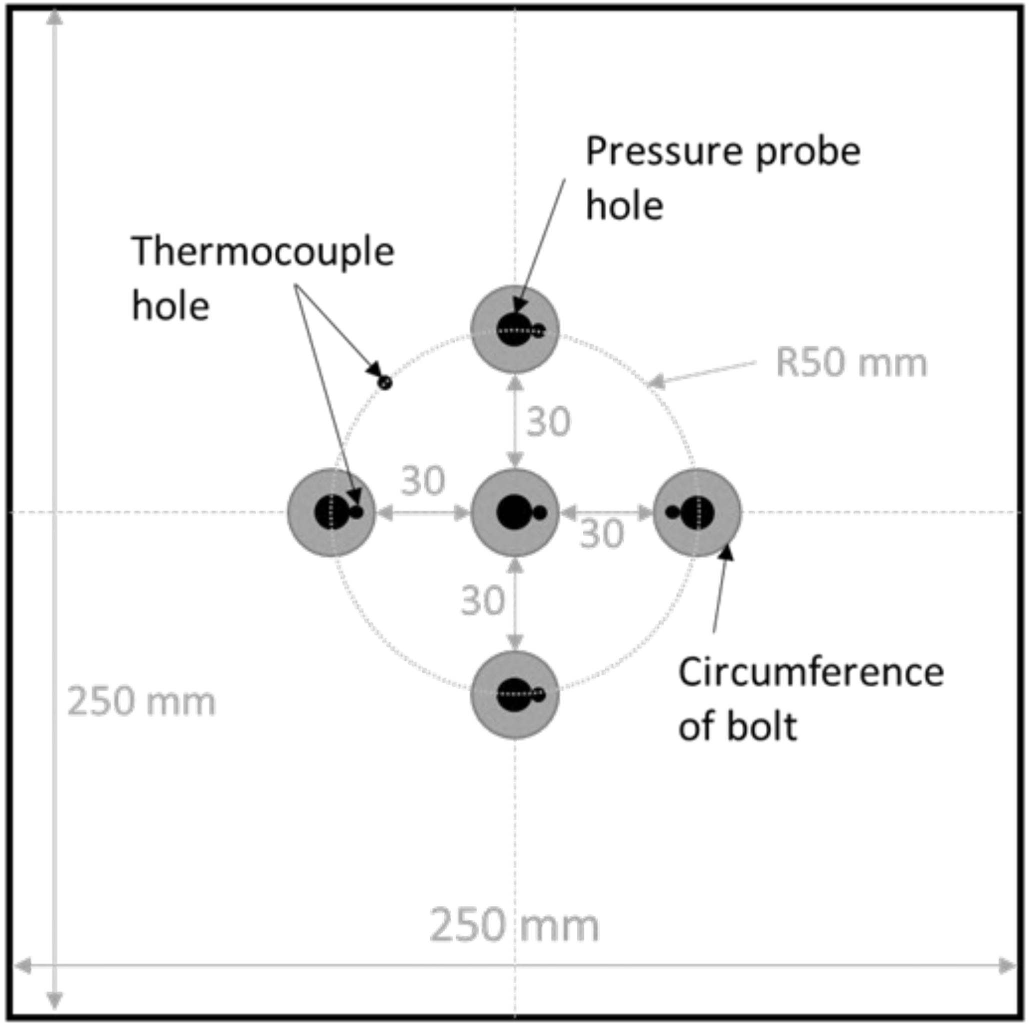


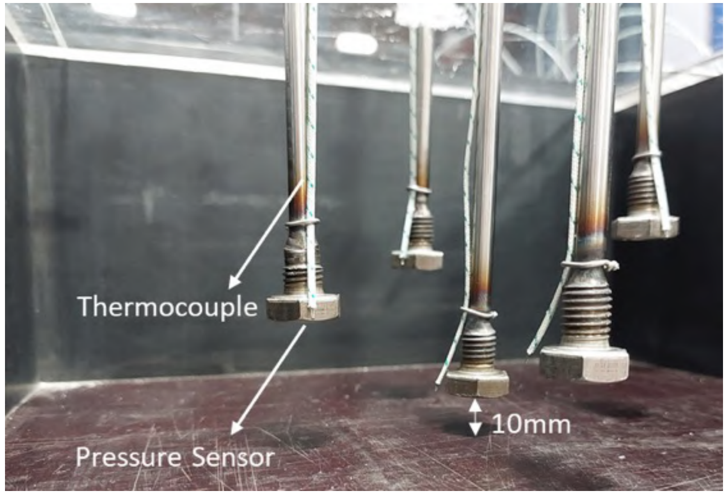
Experimental Work – Overview of Testing Matrix

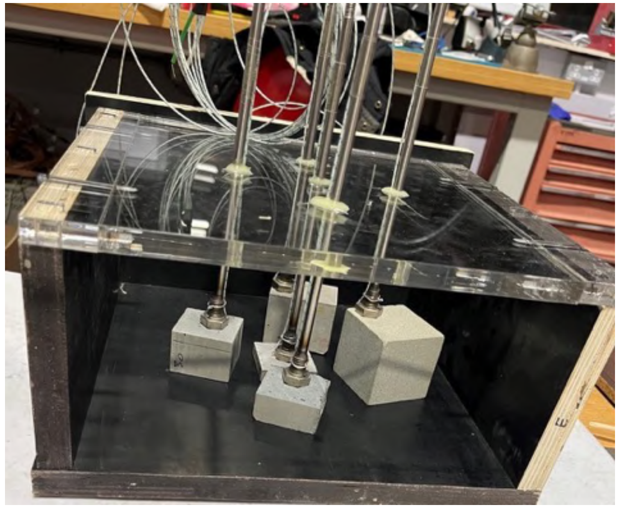
Specimen ID	Test Method
A_1	Maximum Output Case
A_2	Maximum Output Case
B_1	Maximum Output Case
B_2	Maximum Output Case
A_3	ISO Curve Case
A_4	ISO Curve Case
B_3	ISO Curve Case
B_4	ISO Curve Case

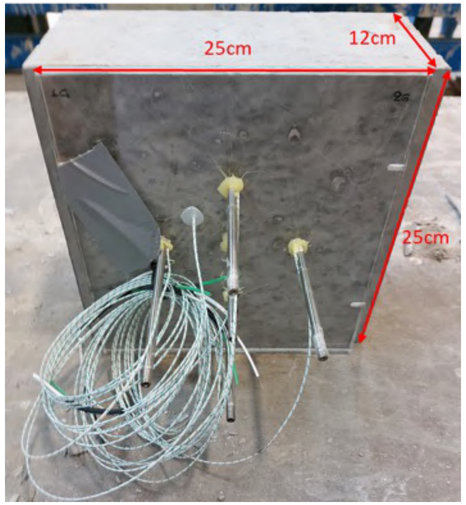


Experimental Work – Instrumentation Layout





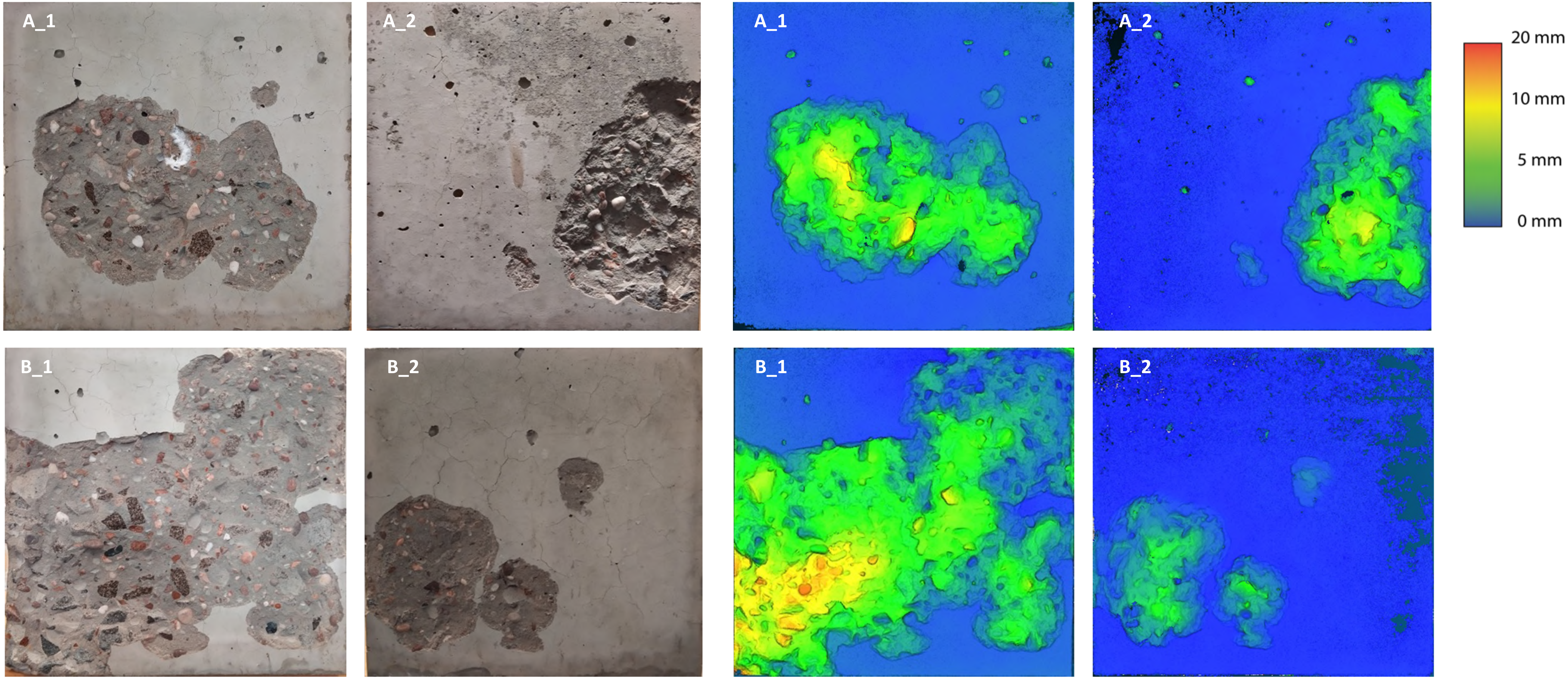




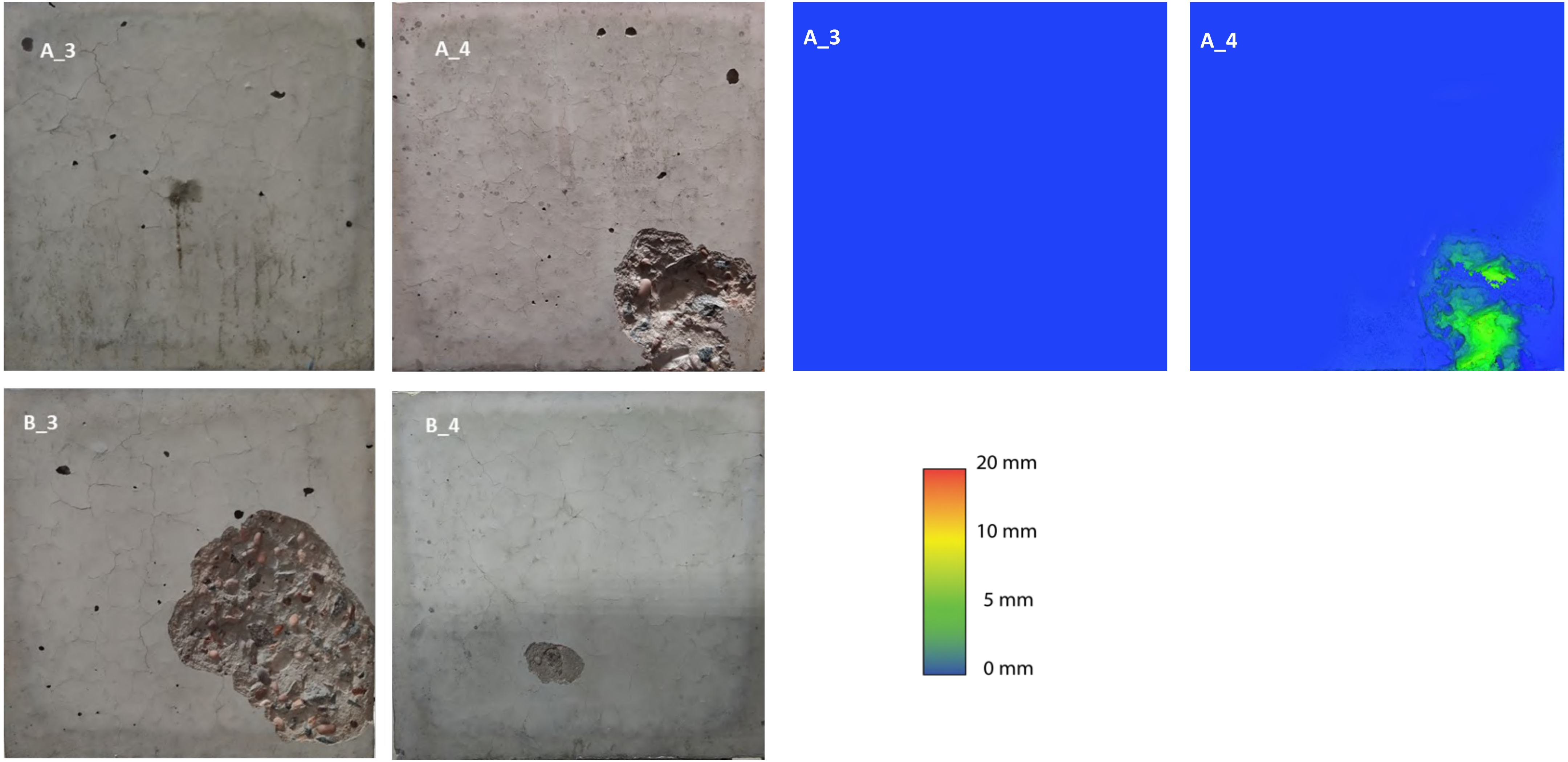
Experimental Work – Overview of Spalling Test Results

Specimen ID	Test Method	Spalling	First Spalling Time	Spalling Mode
A_1	Maximum Output Case	x	3'	Multiple
A_2	Maximum Output Case	x	3'	Multiple
B_1	Maximum Output Case	x	3'	Multiple
B_2	Maximum Output Case	x	3'	Multiple
A_3	ISO Curve Case	-	-	-
A_4	ISO Curve Case	x	14'	Single
B_4	ISO Curve Case	-	-	-
B_3	ISO Curve Case	x	7’	Single

Spalling Profiles – Maximum Output Case



Spalling Profiles – ISO Curve Case



Numerical Work – Modelled Phenomena

Thermal	Hygral
Heat Transfer	Mass Transport
Energy Balance	Mass Balance
⇩	⇩
Temperature Profiles	Pressure Profiles

Numerical Work – Model Structure

Model Parameters

$\varphi_0,\ K_0,\ C_{ps_0},\ \lambda_d$

Constitutive Equations

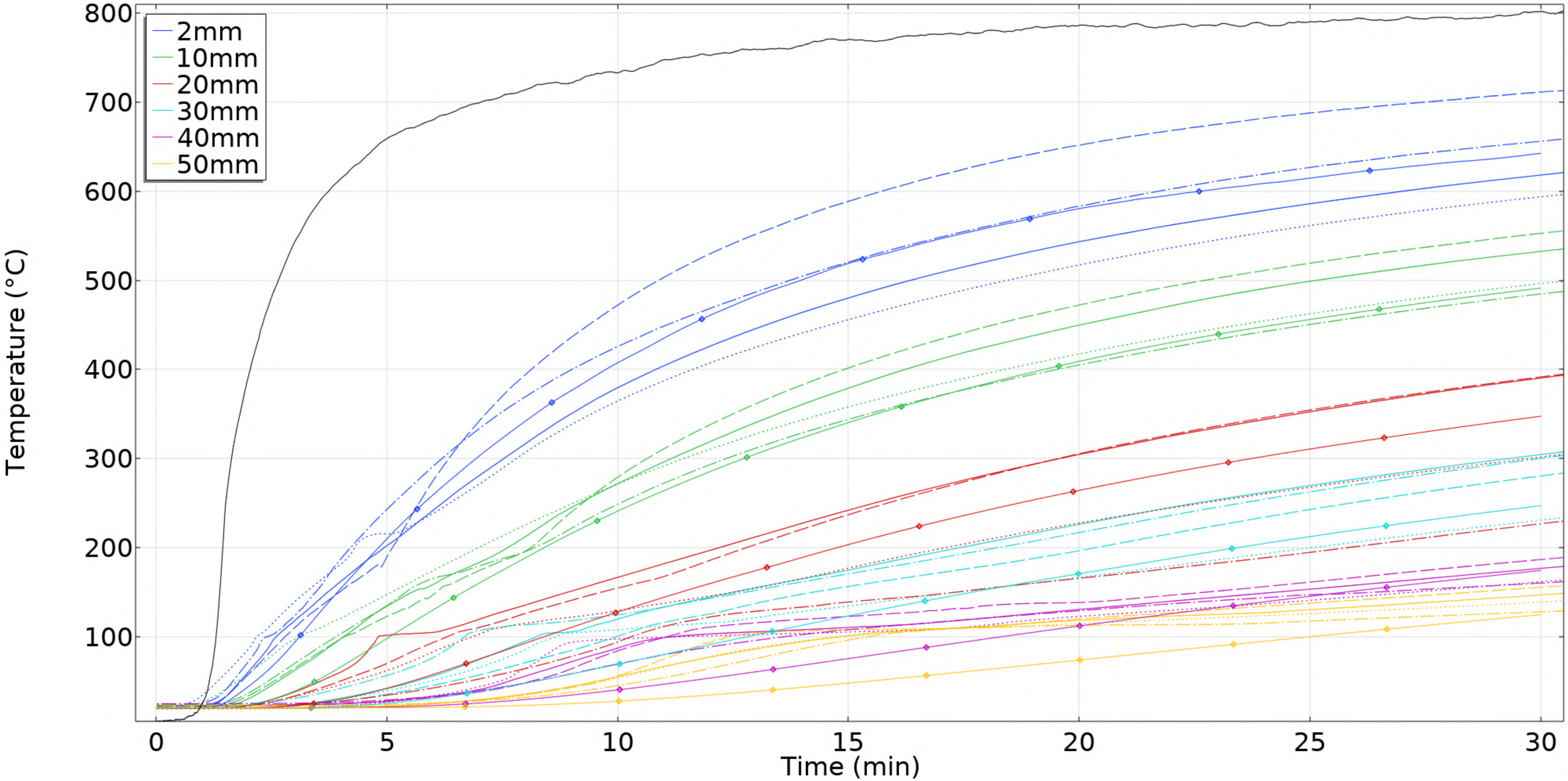
$$S_l = \left(\left(\frac{Ep_c}{a}\right)^{\frac{b}{b-1}} + 1\right)^{-\frac{1}{b}} \qquad \rho_a = p_a \frac{M_a}{RT} \qquad p_v = p_{vs}\exp\left(\frac{-p_c M_w}{\rho_l RT}\right)$$

Conservation Equations

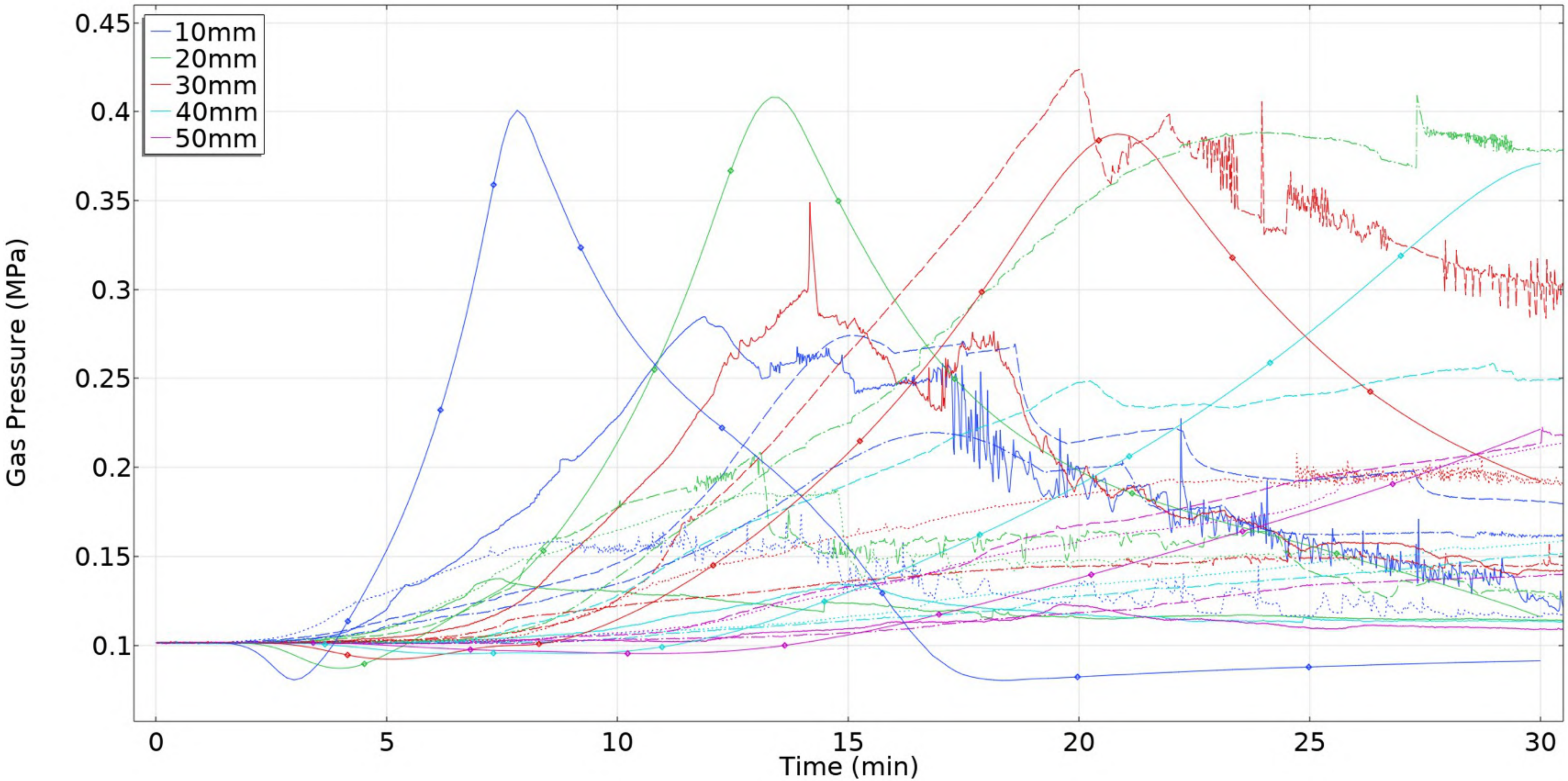
$$\frac{\partial m_a}{\partial t} + \nabla \cdot (J_a) = 0 \qquad \frac{\partial (m_w)}{\partial t} + \nabla \cdot (J_w) = -\ \dot{m}_{deh}$$

$$\rho C_p \frac{\partial T}{\partial t} + \left(m_l C_{pl} v_l + m_g C_{pg} v_g\right) \cdot \nabla T + \nabla \cdot q = \dot{m}_{deh} \Delta H_{deh} - \dot{m}_{vap} \Delta H_{vap}$$

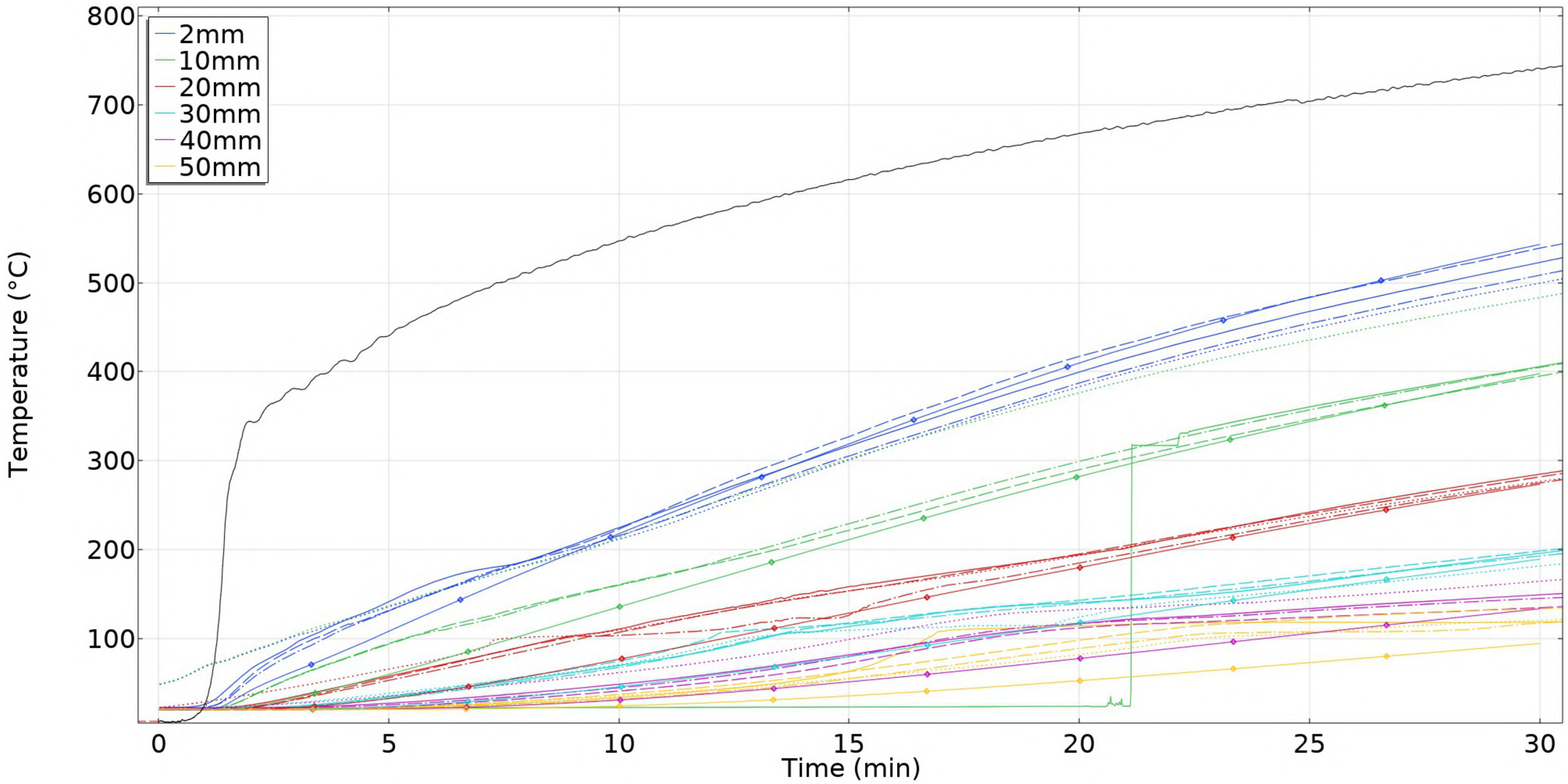
Comparison of Temperature Curves – Maximum Output Case



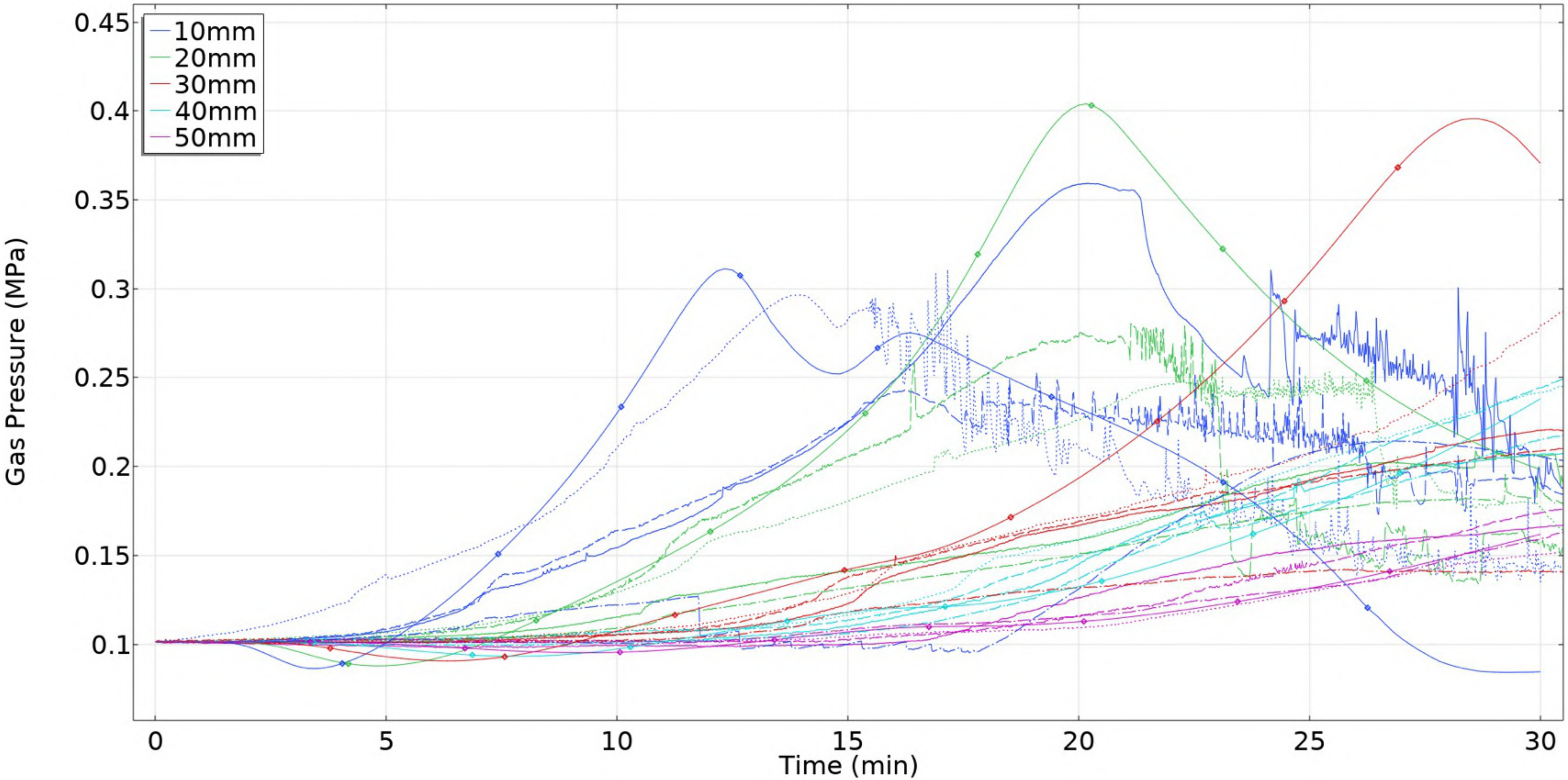
Comparison of Pressure Curves – Maximum Output Case



Comparison of Temperature Curves – ISO Curve Case



Comparison of Pressure Curves – ISO Curve Case



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Thank you!
Any Questions?

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References

[1] Thomas, N. and Pickard, J. (2020) ‘Plan for new UK nuclear plant under intense scrutiny’, *Financial Times*, 2 June. Available at: https://www.ft.com/content/4e3221ef-ac1e-43cc-8d68-e1397ca0637f (Accessed: 20 September 2023).

[2] GOV.UK (2019) GOV.UK: Nuclear Provision: the cost of cleaning up Britain’s historic nuclear sites. Available at: https://www.gov.uk/government/publications/nuclear-provision-explaining-the-cost-of-cleaning-up-britains-nuclear-legacy/nuclear-provision-explaining-the-cost-of-cleaning-up-britains-nuclear-legacy (Accessed: 20 September 2023).

[3] NAMRC (2023) Nuclear AMRC: Industry Intelligence: Nuclear Decommissioning in the UK. Available at: https://namrc.co.uk/intelligence/decommissioning/ (Accessed: 20 September 2023).

[4] TunnelTECH (2012) TunnelTECH: FIRE SPALLING, Fire-spalling of self-compacting concrete. Available at: https://www.tunneltalk.com/TunnelTech-May12-Concrete-fire-spalling.php (Accessed: 20 September 2023).

[5] Jansson, R. (2013) Fire spalling of concrete: Theoretical and experimental studies. PhD thesis. KTH Royal Institute of Technology.