Investigation of the Non-adiabatic Thermoelastic Effect in Face-sheet/core Debonded Composite Sandwich Structures

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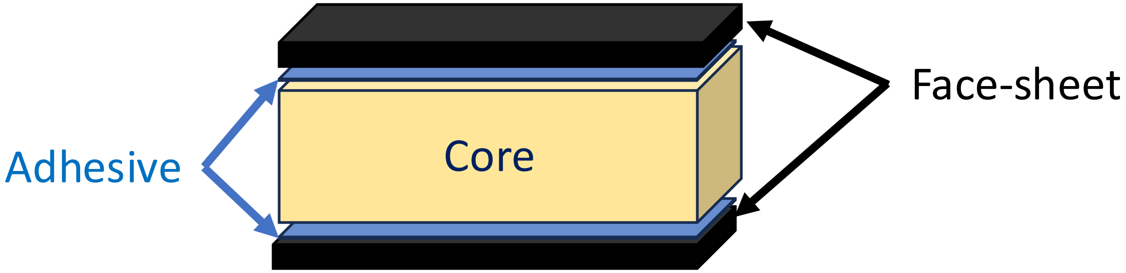
Motivation

Composite Sandwich Structures

- High bending stiffness and strength to weight ratio



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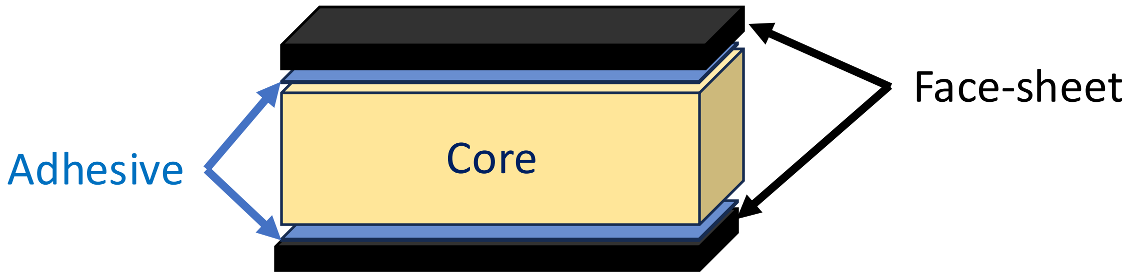

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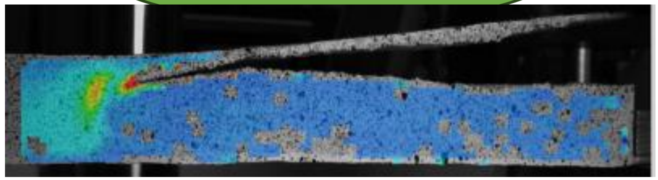
Background

Damage in sandwich structures

- Reduce stiffness and strength

Full-field imaging techniques
+ FE analysis

View of
damaged area



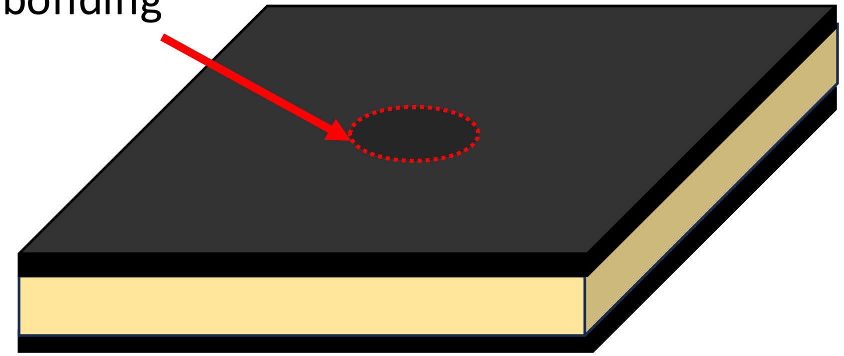
Martakos et al [1]

Previous studies

- Crack tip
- Subsequent damage propagation

at the face-sheet/core interface can be identified

Face-sheet/core
debonding



Large structures

- Difficult to access and view hidden damaged area

[1] Martakos G, Andreasen J, Berggreen C, Thomsen O. Experimental investigation of interfacial crack arrest in sandwich beams subjected to fatigue loading using a novel crack arresting device. Journal of Sandwich Structures & Materials. 2019;21(2):401-421. doi:10.1177/1099636217695057

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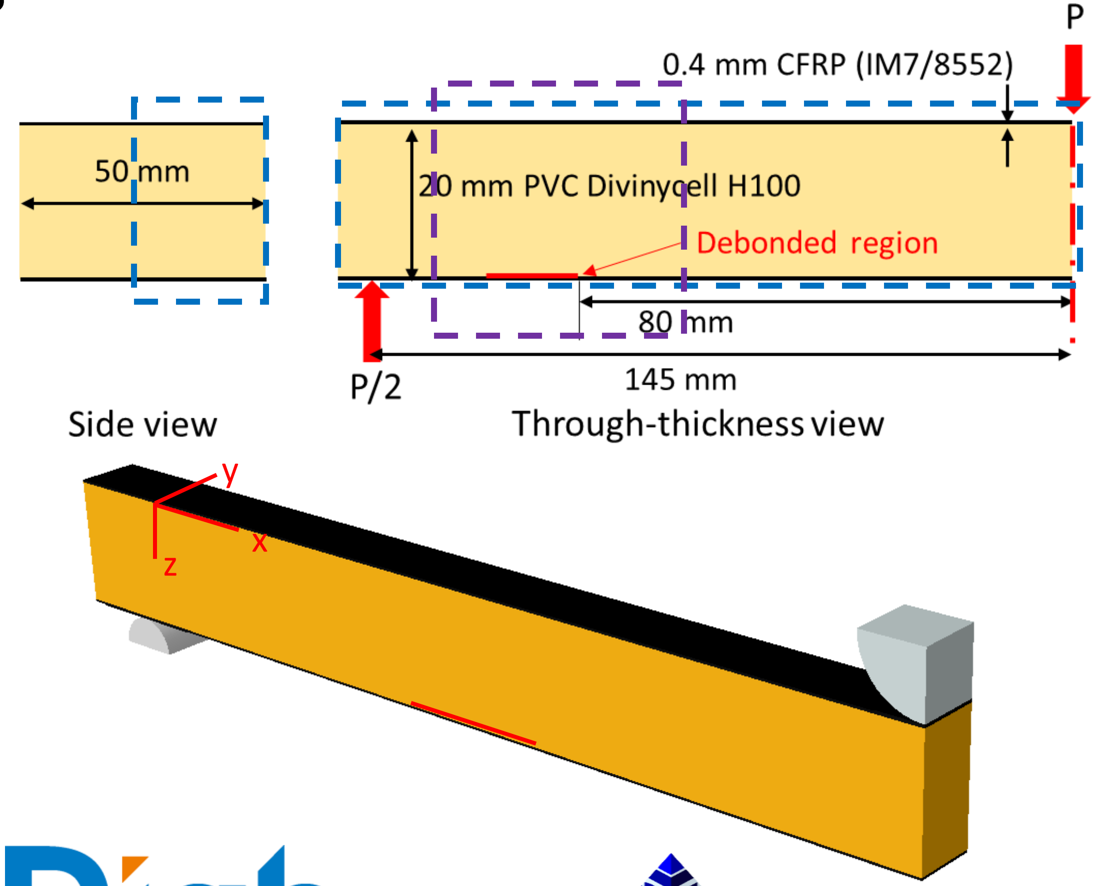
Aims/Objectives

Investigate the non-adiabatic thermoelastic response at the face-sheet/core interface in sandwich beams

- Assessing defect severity through through-thickness view
- Model validation using experimental data
- Investigating heat transfer at the interface using numerical models and experimental data



Thermoelastic stress analysis (TSA)

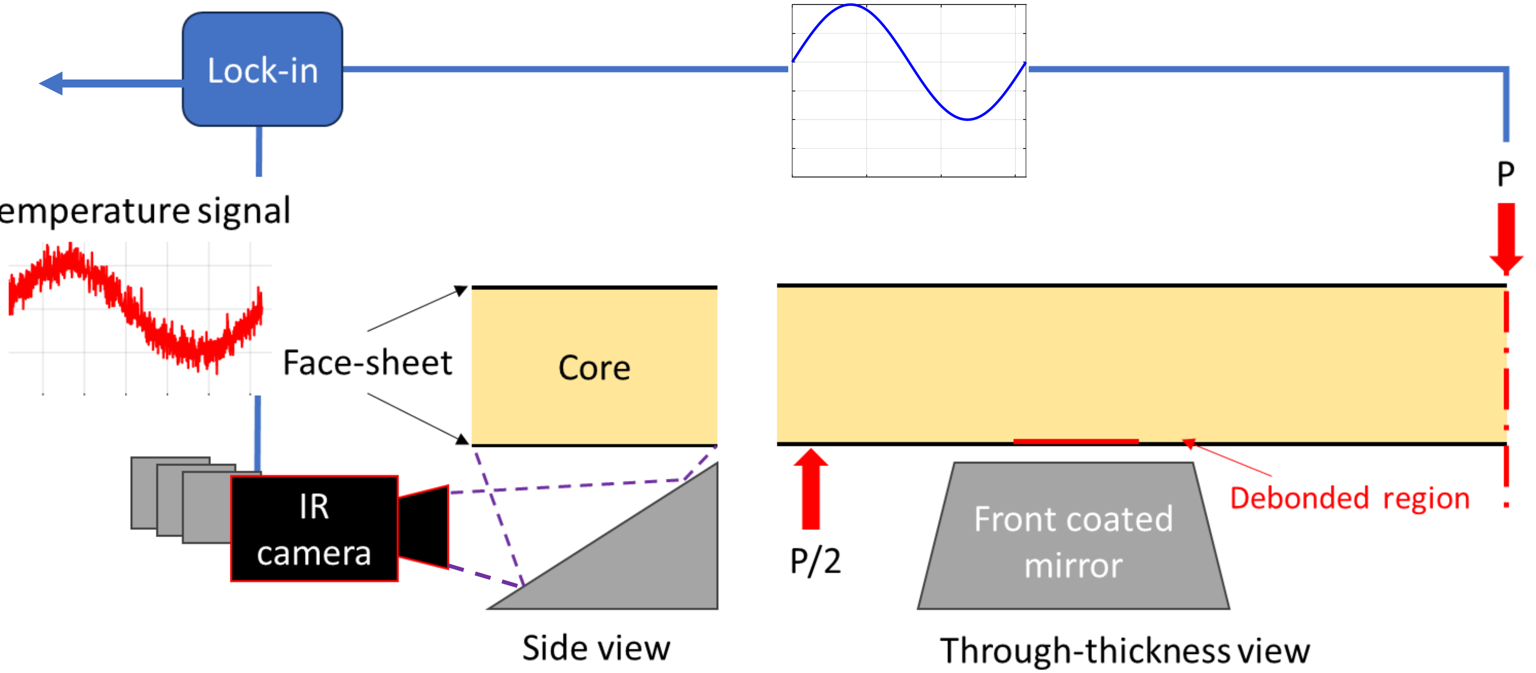
TSA utilizes the thermoelastic effect to correlate the temperature variations and the stresses in a structure subjected to elastic cyclic loading

Thermoelastic response, ΔT

$$\dot{T} = \frac{T_0}{\rho C_\varepsilon}\frac{d\sigma_{ij}}{dT}\dot{\varepsilon}_{ij} - \underbrace{\cancel{\frac{\dot{Q}}{\rho C_\varepsilon}}}_{\text{Heat transfer term}} \quad \text{for } i, j = 1, 2, 3$$

$$\frac{\Delta T}{T_0} = -\frac{(\alpha_1 \Delta\sigma_1 + \alpha_2 \Delta\sigma_2)}{\rho C_p}$$

A high loading frequency is used to ensure adiabatic conditions



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Non-adiabatic thermoelastic response

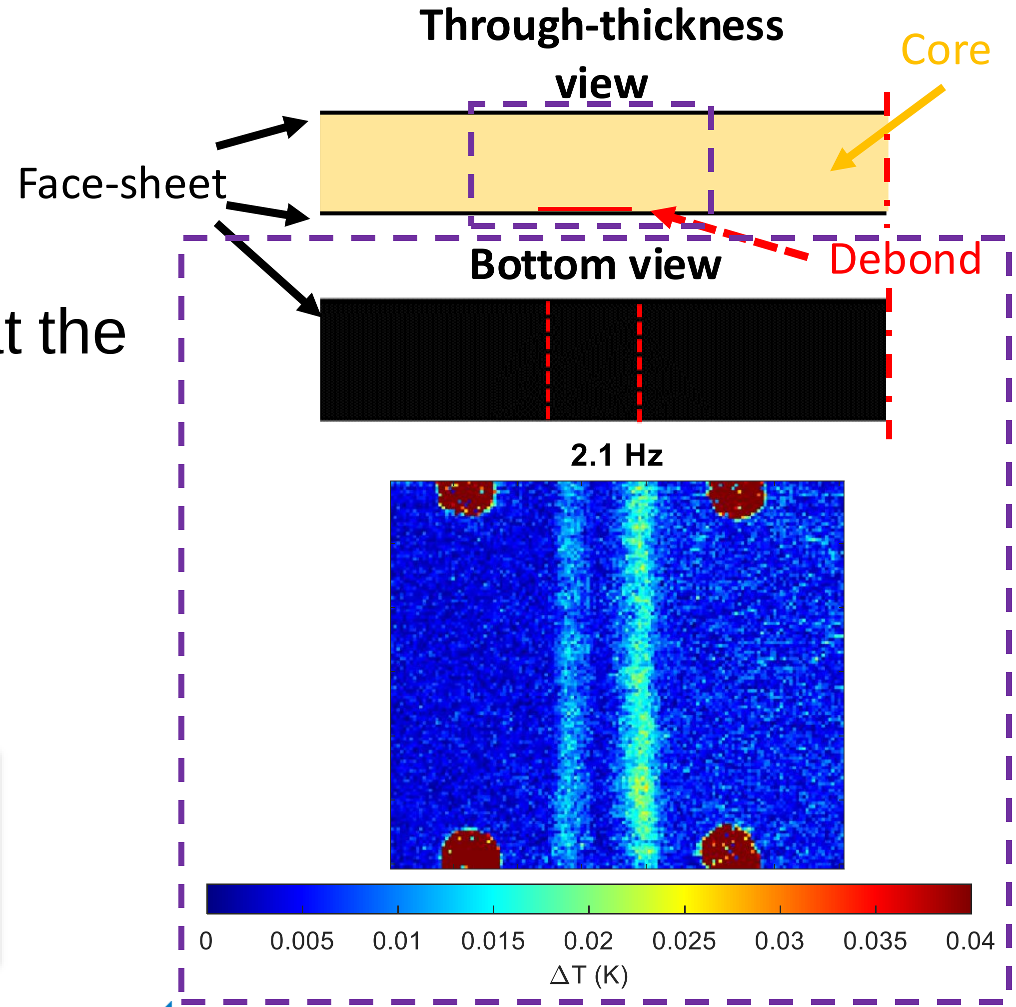
Multidirectional carbon fibre composites

- High thermal gradients
  - Heat transfer at low loading frequencies
- Subsurface plies influence the temperature at the surface

Identified interface debond regions

- Through the face-sheet
- Non-adiabatic thermoelastic response

<u>Can this be related to the damage severity at the interface?</u>



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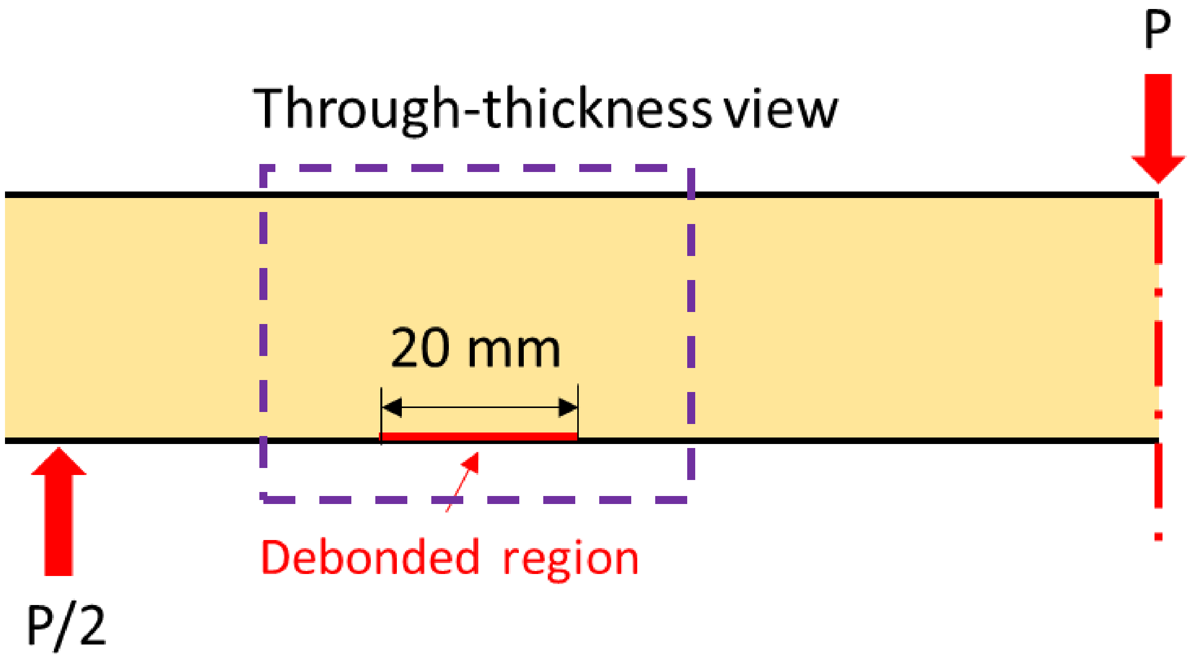
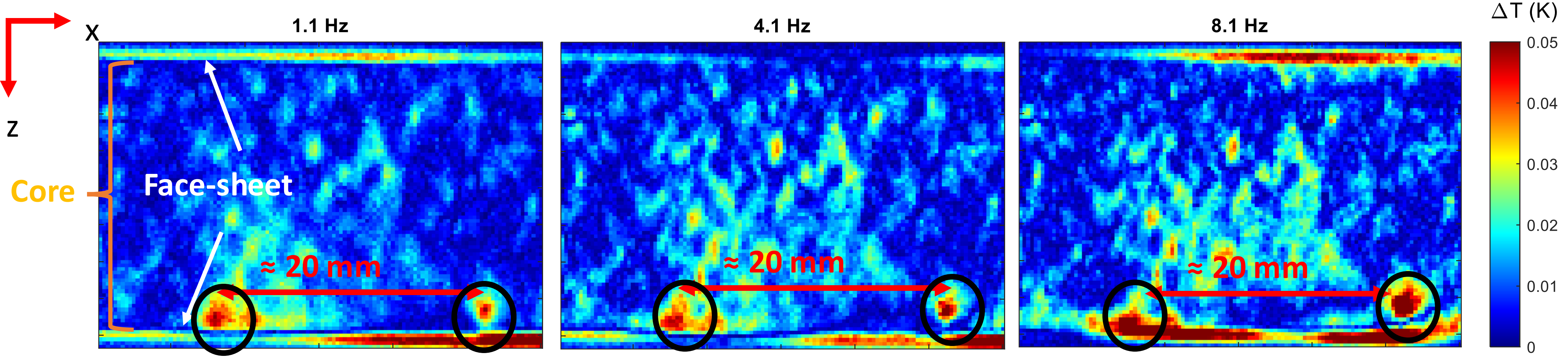
Experimental methodology

- Face-sheet – unidirectional CFRP
- Core - PVC
- Teflon film is used to create debonded region
- Loading: -500N ± 400 N
- Frequency: 1 - 11 Hz



Thermoelastic responses at through-thickness view



Two high ΔT areas at the core

ΔT increases with loading frequency

Distance between high ΔT areas ≈ debond size

Low signal at the face-sheets and core

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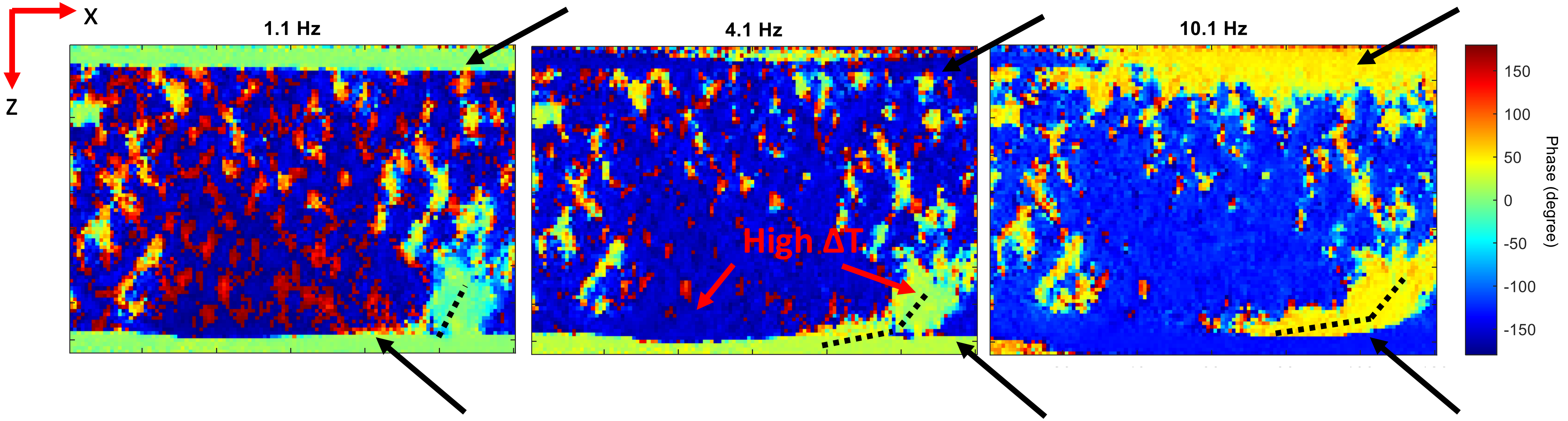
Phase at through-thickness view



Top face-sheet in compression

Bottom face-sheet in tension

Face-sheets ≈ opposite in phase as the loading frequency increases

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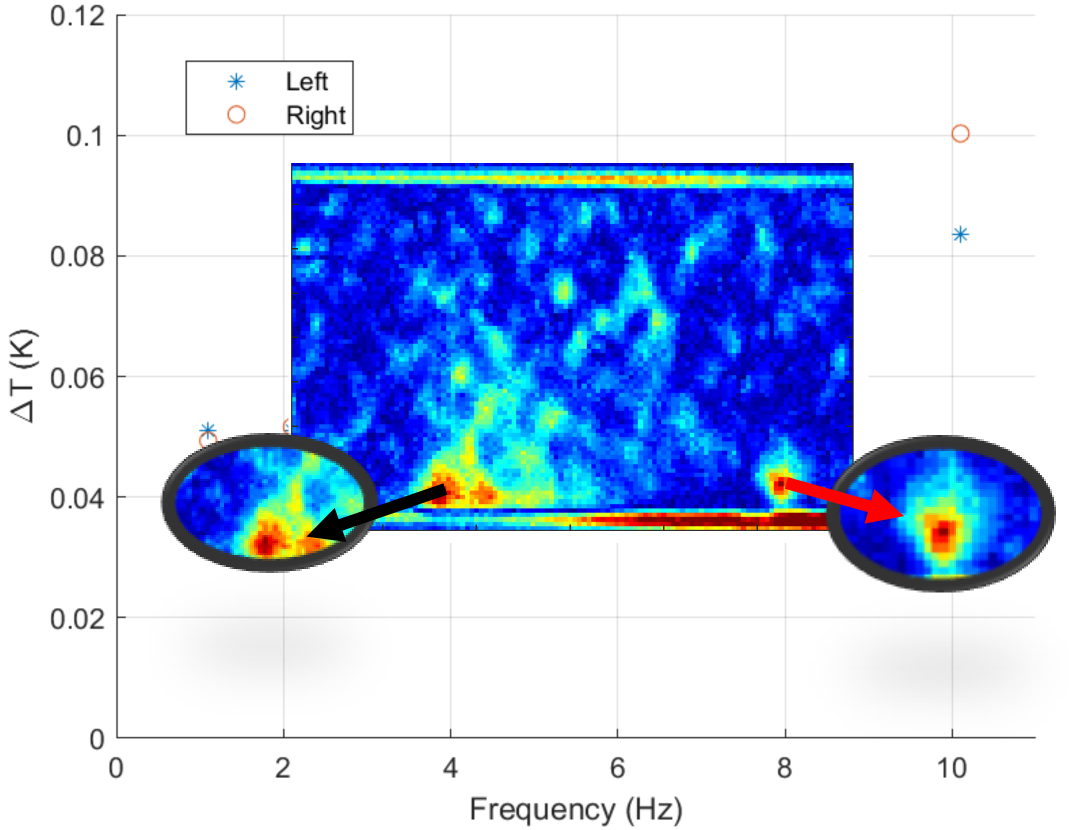
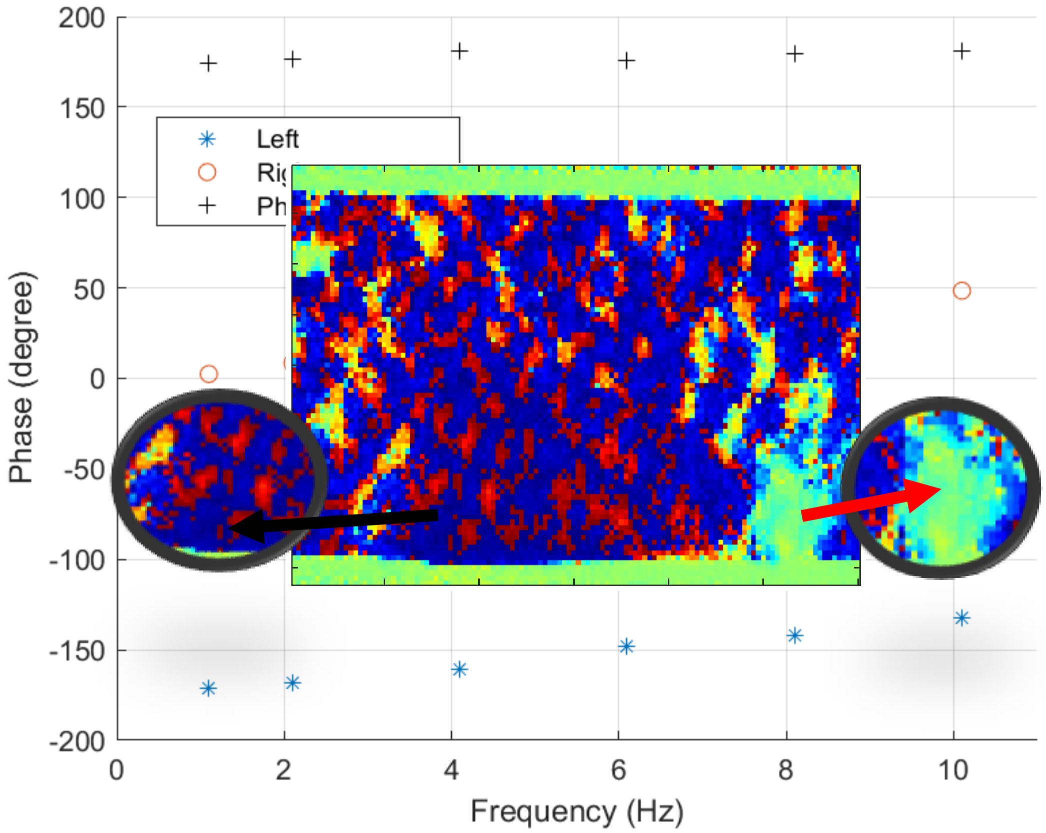
ΔT and Phase


Left
Right
0.12
0.1
0.08
0.06
0.04
0.02
0
ΔT (K)
0
2
4
6
8
10
Frequency (Hz)


Left
Phase (degree)
200
150
100
50
0
-50
-100
-150
-200
0
2
4
6
8
10
Frequency (Hz)

Modelling details

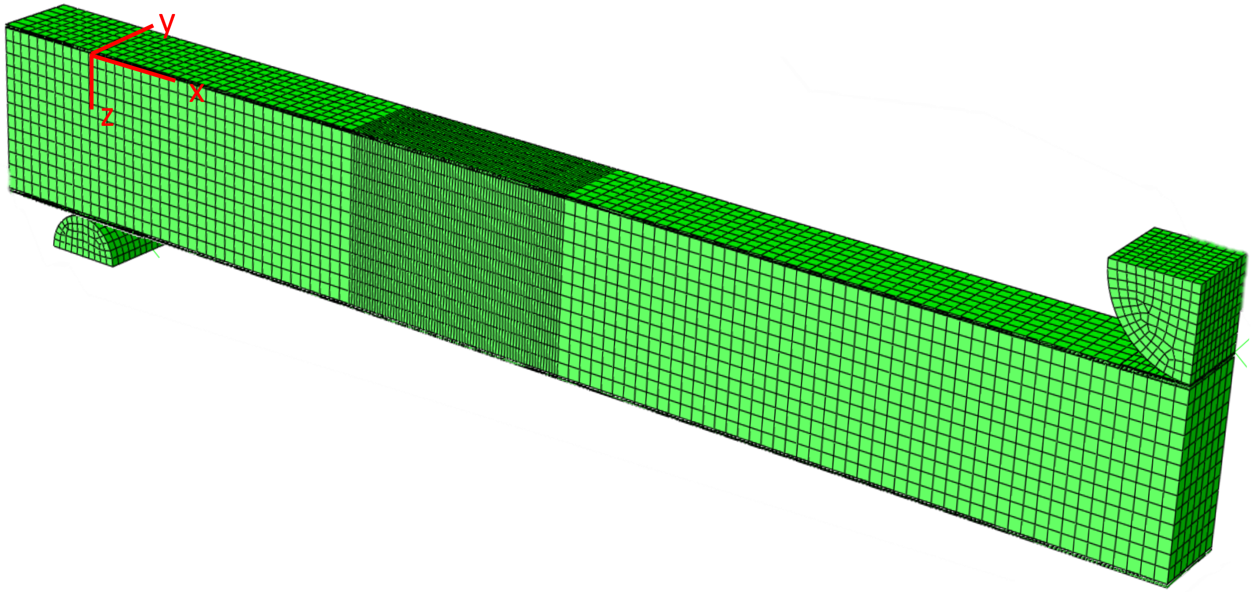
Geometric non-linear model

Element type

- C3D20RT-20-node coupled temperature-displacement elements (face-sheet and core)
- Global element size = 1.5 mm
- Refined element size at the debonded region= 0.4 mm

Total number of elements: 31476

Total number of nodes: 92746



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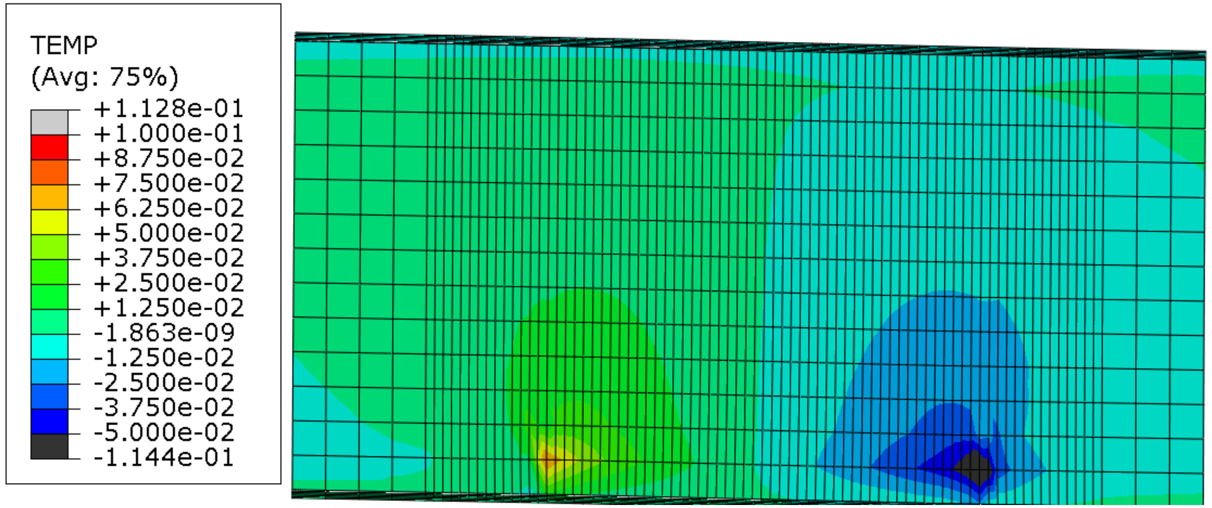
Thermoelastic effect in FE model

Fortran user subroutine (developed in [2]) is used to generate synthetic TSA data

As an addition to the model, heat transfer is allowed at the debond region by using thermal contact.

- Teflon PTFE thermal properties



[2] Cappello, R., Pitarresi, G., Catalanotti, G.: Thermoelastic Stress Analysis for composite laminates: A numerical investigation. Compos Sci Technol. 241, 110103 (2023).https://doi.org/10.1016/J.COMPSCITECH.2023.110103

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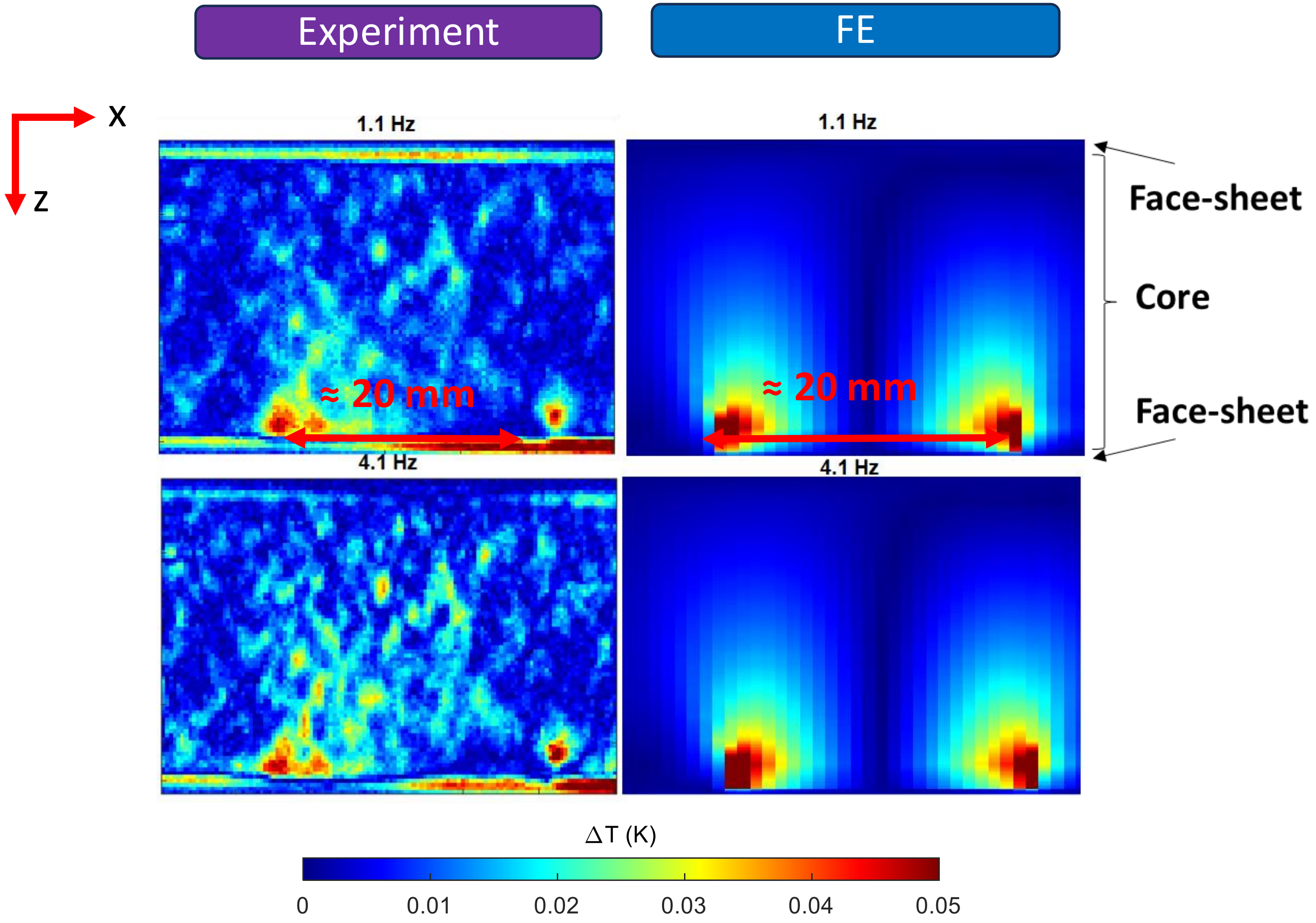
FE and Experiment (Full-field ΔT)



High ΔT at the core

The distance between the high ΔT ≈size of the debond

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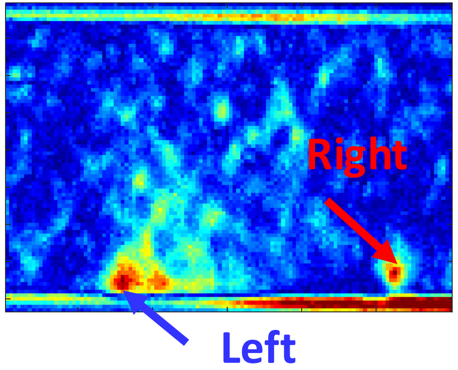
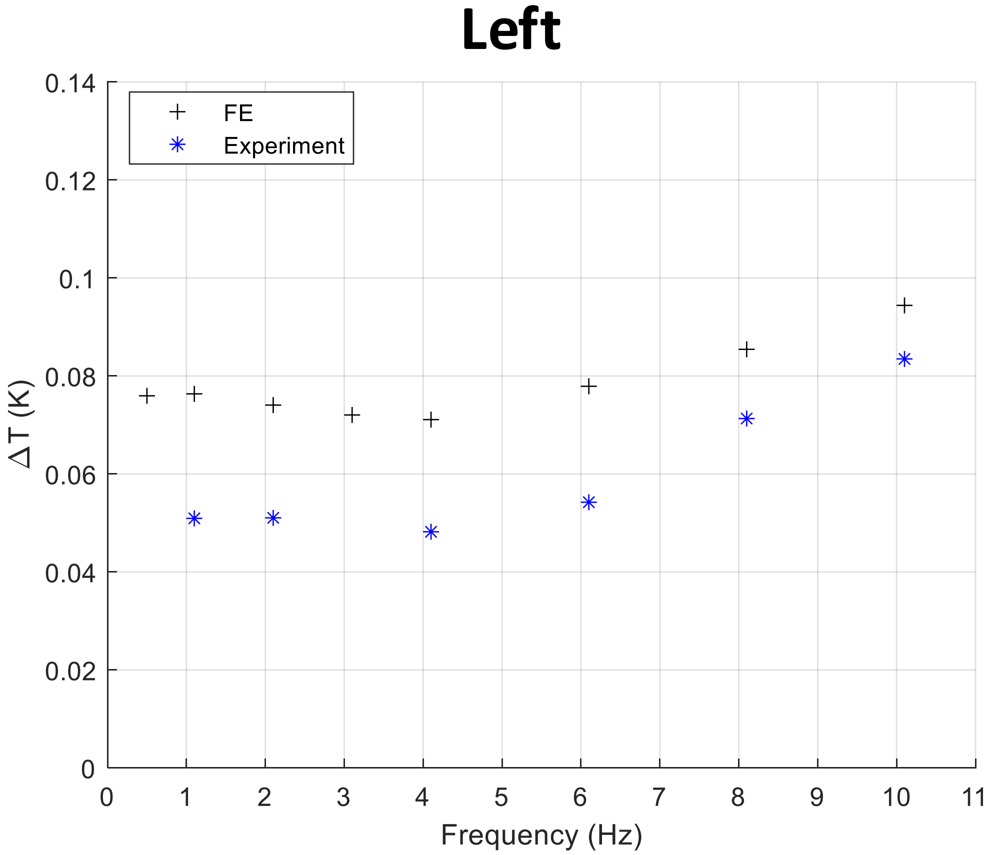
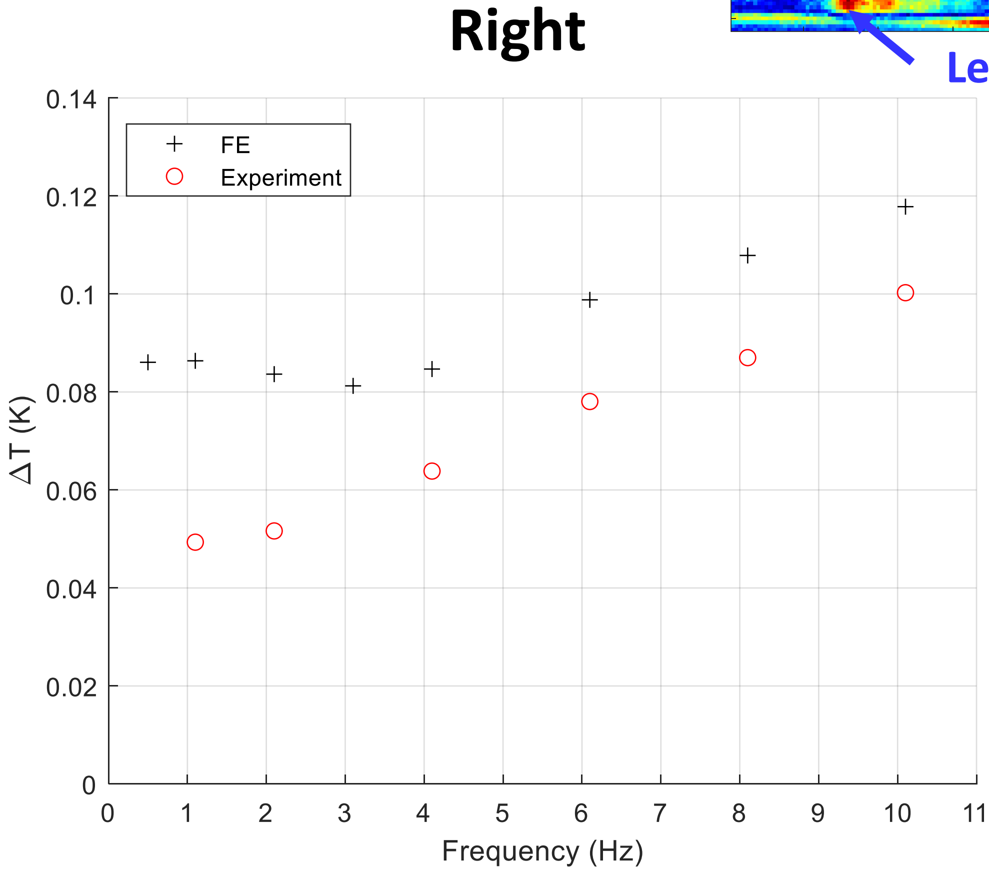
FE and Experiment (ΔT)







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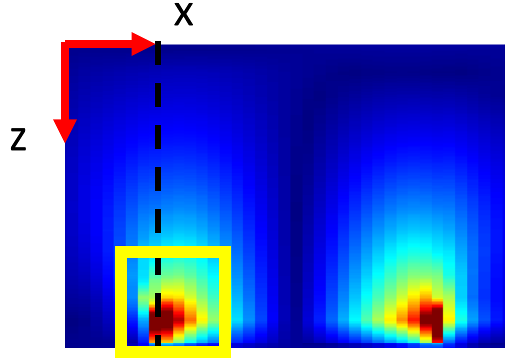
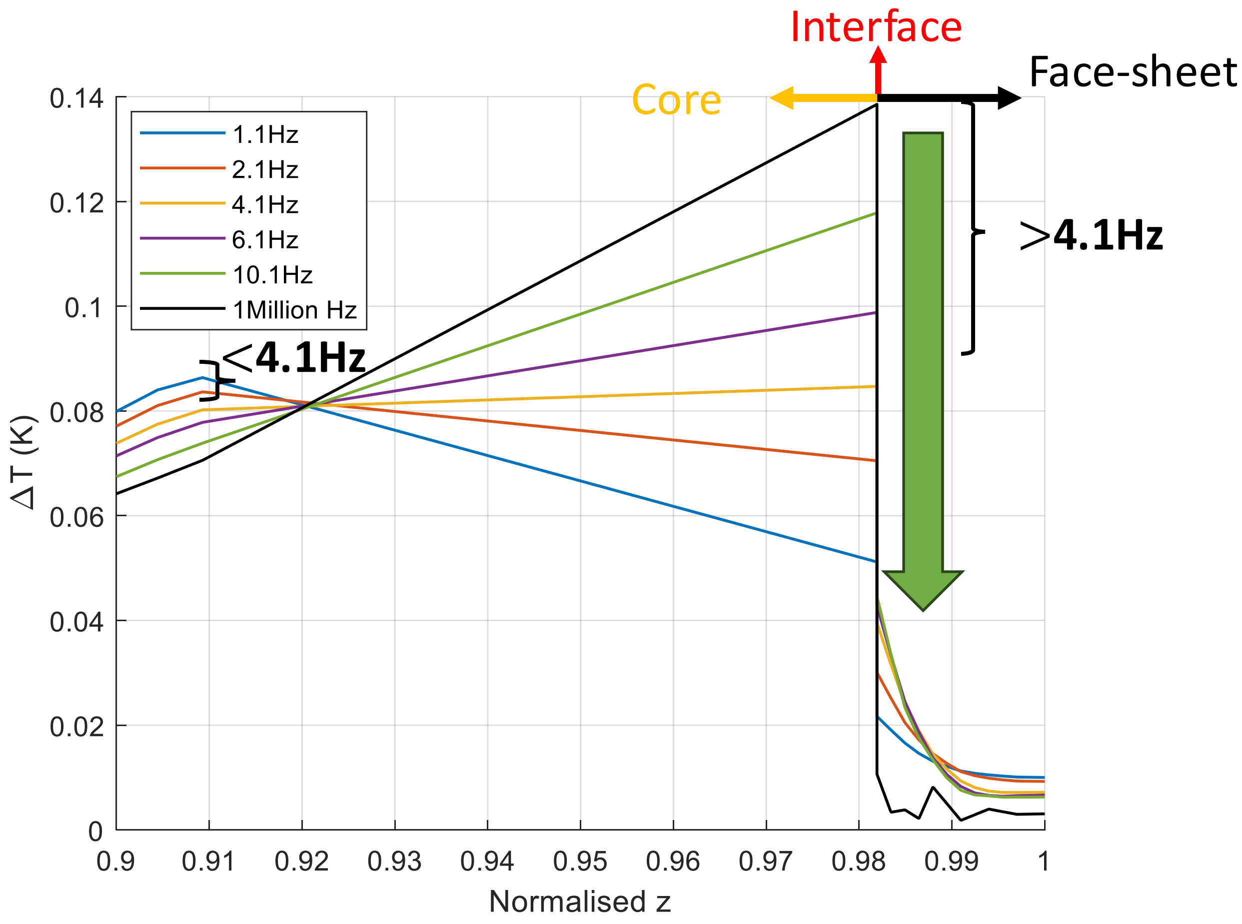
ΔT -Through–thickness study (FE)





1 million Hz - adiabatic response

- ΔT interface discontinuity is largest
- As heat transfer increases, these difference is reduced

When heat transfer occurs

Core is the heat source

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Summary and Future work

General agreement between FE and experimental results

- Adopting DIC for motion compensation

FE results

- As the loading frequency increases
  - High thermoelastic responses move from the core to the interface
- Core material is the heat source

Potential of correlating the surface thermoelastic response with damage severity

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