Thermo-mechanical Analysis and Anisotropy Analysis of SiC_f/SiC Composites for Low-stress SCYLLA Breeding Blanket Modules

Luigi Candido, Colin Baus, Ben Raeves, Richard Pearson, Jack Taylor
Kyoto Fusioneering UK Ltd., United Kingdom

Italo Godoy-Morison, Reuben Holmes, Taishi Sugiyama
Kyoto Fusioneering Ltd., Japan

A. René Raffray
University of California, San Diego, USA

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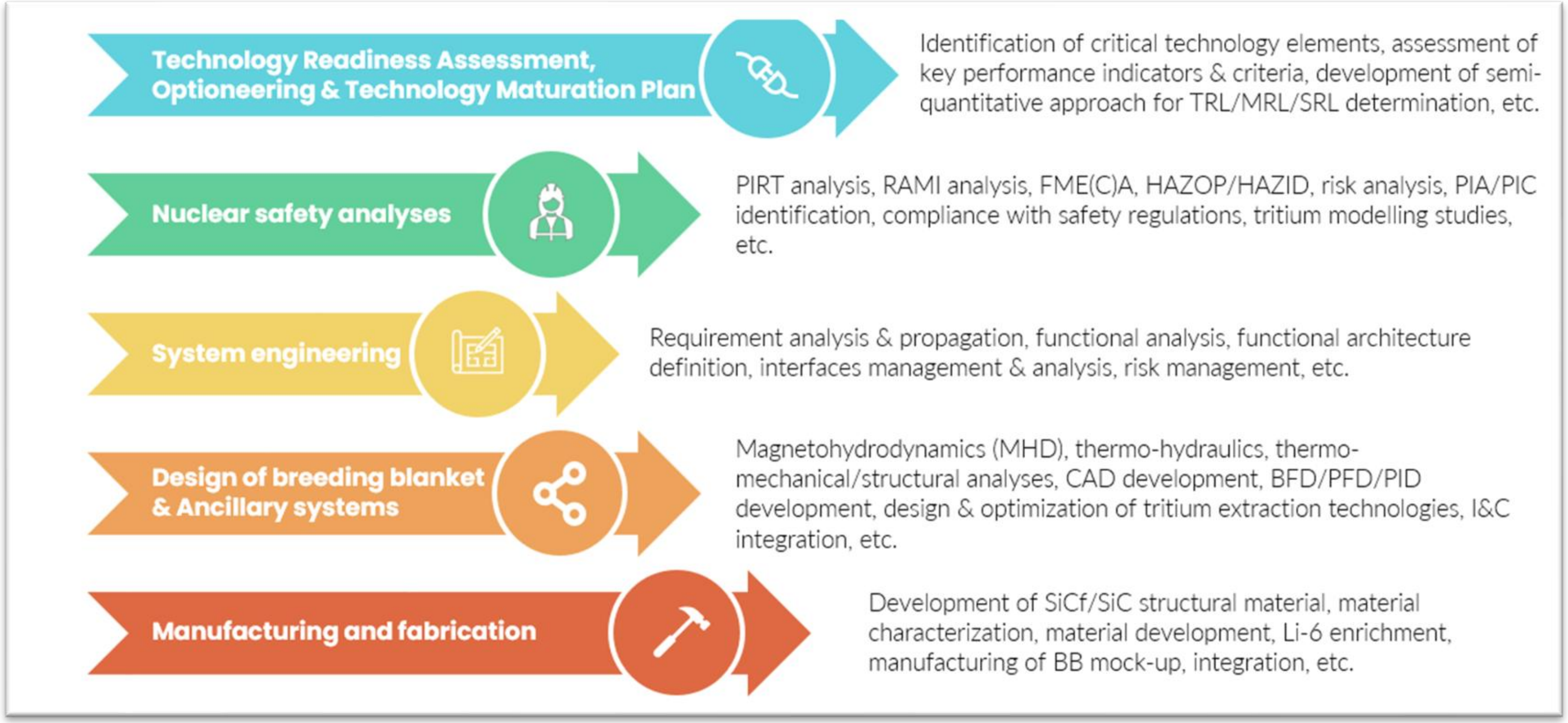
01 SCYLLA Blanket Concept and Objectives

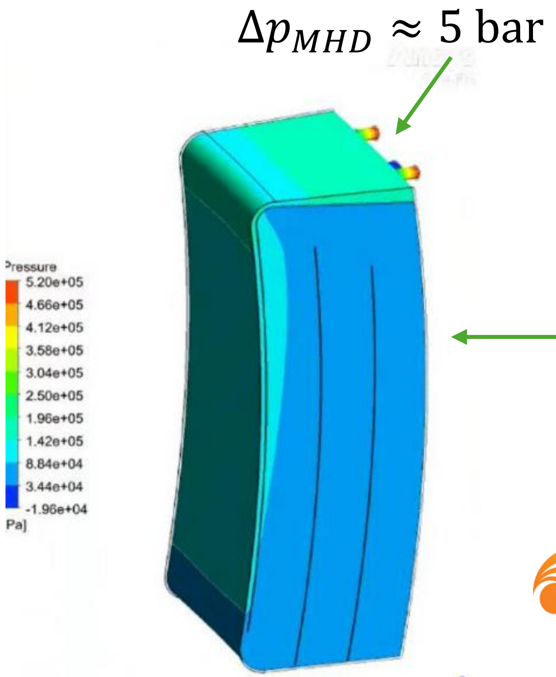
- **SCYLLA** (Self-Cooled Yuryo Lithium-Lead Advanced) is a cutting-edge breeding blanket concept developed by Kyoto Fusioneering, utilising **SiC_f/SiC composite** materials and **LiPb** as both breeder and coolant, tailored for high-performance fusion environments.
- SiC_f/SiC enables **high-temperature operation**, while significantly reducing **tritium permeation and magnetohydrodynamic (MHD) losses**, making it a key enabler for efficient and commercially viable breeding blanket systems.
- In collaboration with **UKAEA**, the project aims to design a SCYLLA blanket concept optimized for **Spherical Tokamak** configurations, integrating advanced neutronics, thermo-mechanical, thermo-hydraulics, and tritium transport analyses.
- The scope includes investigative research into materials, configurations, safety, cost assessments, and commercialisation pathways, positioning SCYLLA as **a key enabler for next-generation fusion reactor systems**.

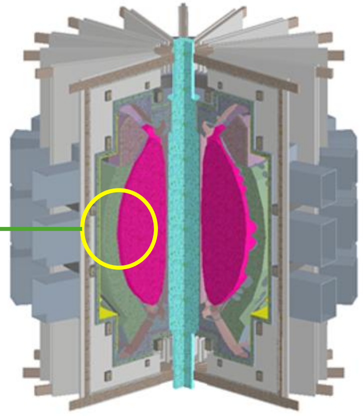


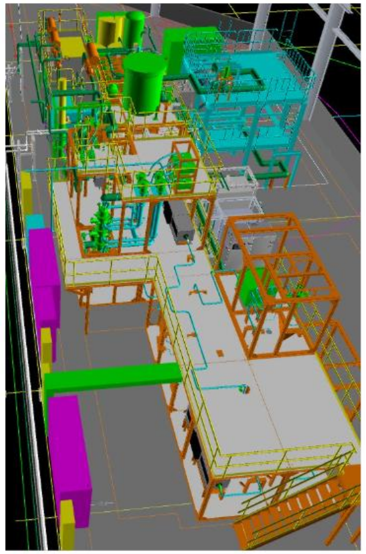
01 SCYLLA Blanket Concept and Objectives

KF is supporting SCYLLA development through:

- **Development of SiC_f/SiC** via HIP (Hot Isostatic Pressing) and HUP (Uniaxial Hot Press)
- Advancing **joining techniques** (such a SiC plate butt sintering or SiC_f/SiC fibre weaving) to allow for large component manufacturing
- **MHD activities**:
  - ➢ Design of MHD test section (KF).
  - ➢ Producing simulation code for numerical MHD analyses through INFUSE programme with PPPL.
  - ➢ Optimisation of the design of the blanket.
- Integration of **RH/RM considerations** into the design from the scratch (RACE)
- **Integrated testing** in UNITY-1 loop in JP:
  - ✓ Testing of diagnostic tools
  - ✓ Thermomechanical and fluid dynamics analysis of blanket mockups
  - ✓ MHD effects studies
  - ✓ Hydrogen transport and extraction experiments
  - ✓ Material corrosion and compatibility assessments
  - ✓ High temperature auxiliary technologies
  - ✓ Advanced energy conversion technology



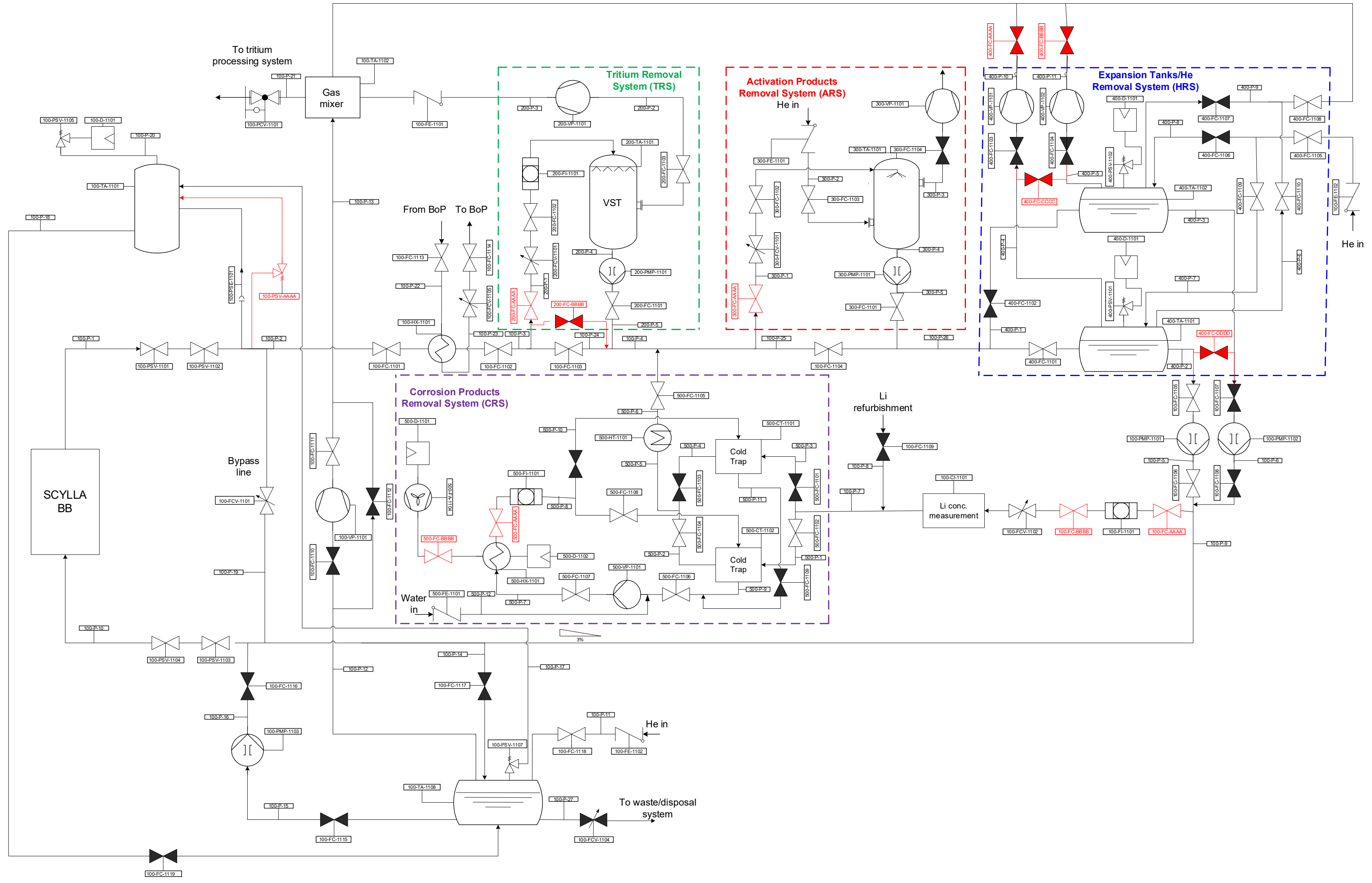




01 SCYLLA Blanket Concept and Objectives

- The blanket is a complex, fully integrated system…

Valves open/closed are referred to POS



Legend

LLP: lithium-lead loop
TRS: tritium removal system
ARS: activation removal system
HRS: helium removal system
CRS: corrosion removal system

01 SCYLLA Blanket Concept and Objectives

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Commercial and technical viability of SCYLLA blanket

Skill and competencies

Provide an instrument for technology development

Integrated blanket design

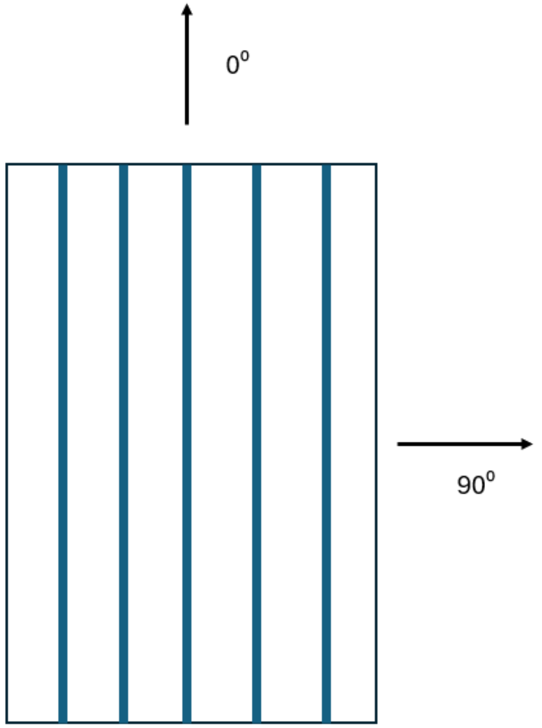
Design alternatives

Mock-up manufacturing and testing

Building on the success of our initial concept studies (SCS – Phase 1), we now enter a critical phase (SCS – Phase 2) of detailed thermo-mechanical analysis, with a focus on stress reduction and iterative design improvements informed by emerging insights.

02 Anisotropy Characterization of SiC_f/SiC Laminates

- SiC_f/SiC is a **composite material**, consisting of SiC fibres suspended in a SiC matrix.
- The relationship between the direction of the fibres and the load direction has **profound effects** on the mechanical response and strength of the composite.
- For example, some **mechanical properties** for a unidirectional (UD) composite are given for the longitudinal (0^o to the fibres) and transverse (90^o to the fibres) directions.



	0°	90°
E (GPa)	320	135
ν	0.21	0.09
σ_{UTS} (MPa)	160	25
ε_{UTS} (%)	0.068	0.019

[1] NOZAWA, T., et al., Determination and prediction of axial/off-axial mechanical properties of SiC/SiC composites., Fus. Eng. Des. 87 (2012) 803-807

- This shows that, for UD composites at least, treating SiC_f/SiC as an isotropic material to simplify analysis could lead to **inaccurate results**.

02 Anisotropy Characterization of SiC_f/SiC Laminates

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Classical Laminate Theory (CLT)

It is critical to gain an understanding of how the **mechanical properties** vary with direction, and how **layers orientated differently** from each other affects this. **CLT** allows these properties to be found for any laminate, given the following assumptions are valid:

1. The laminate thickness is very small compared to its other dimensions.
2. The lamina (layers) of the laminate are perfectly bonded.
3. Lines perpendicular to the surface of the laminate remain straight and perpendicular to the surface after deformation.
4. The laminae and laminate are linear elastic.
5. The through-thickness stresses and strains are negligible.

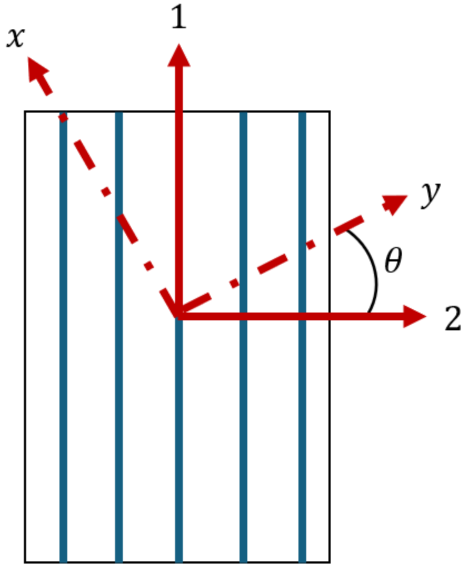
At this stage, to simplify the analysis, the laminates are assumed to always be **symmetrical** and only purely **in-plane loads** are considered.

CLT was implemented in MATLAB, compared with experimental results, and used to identify potential layups to be used in SCS.

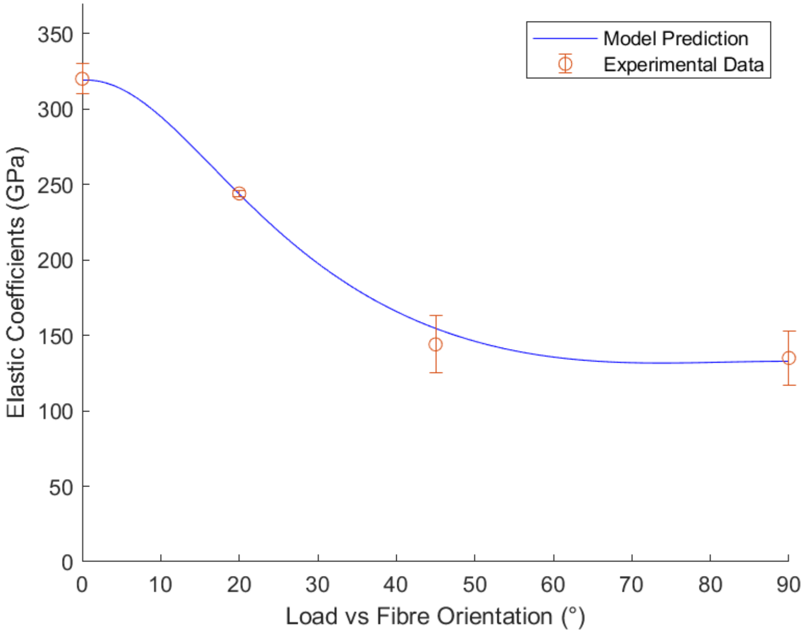
02 Anisotropy Characterization of SiC_f/SiC Laminates

Validation

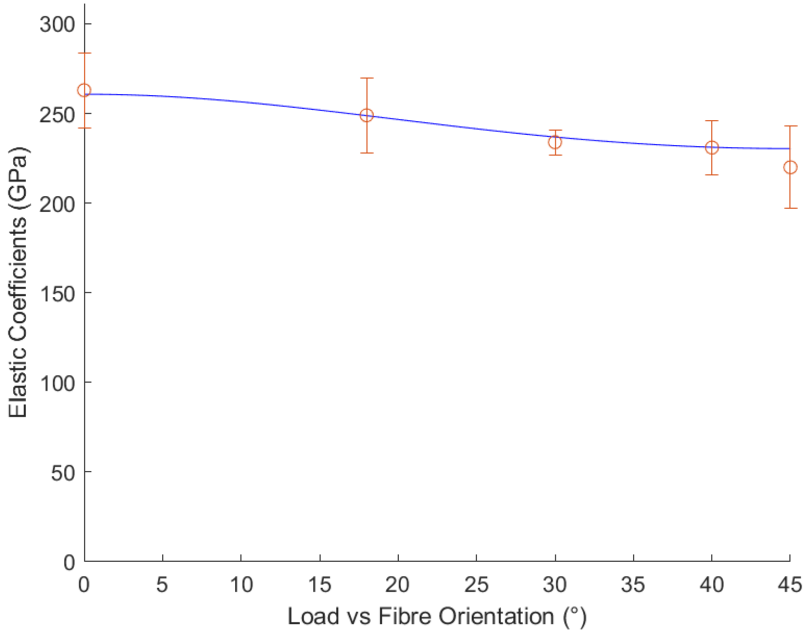
To ensure that CLT is an appropriate model to analyse SiC_f/SiC composites, the model is compared with experimental results for **(1) UD NITE**, **(2) plain-weave (P/W) CVI**, and **(3) P/W NITE** [1]. The figures below show the comparison between the model and the experimental data for elastic modulus.



(1)



(2)



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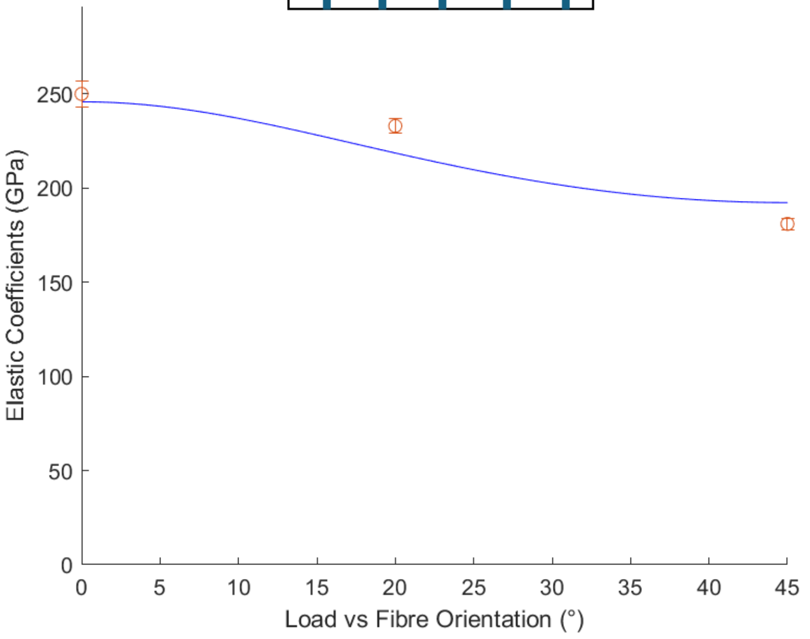


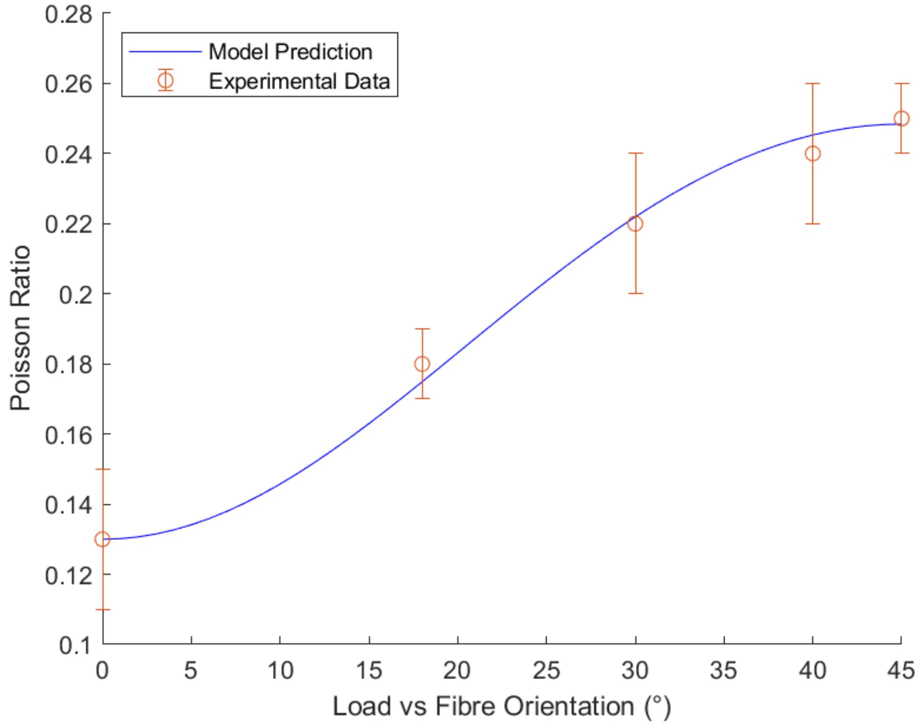
[1] NOZAWA, T., et al., Determination and prediction of axial/off-axial mechanical properties of SiC/SiC composites., Fus. Eng. Des. 87 (2012) 803-807

02 Anisotropy Characterization of SiC_f/SiC Laminates

Validation

The figures below show the comparison between the model and the experimental data for Poisson's ratio:

(2)



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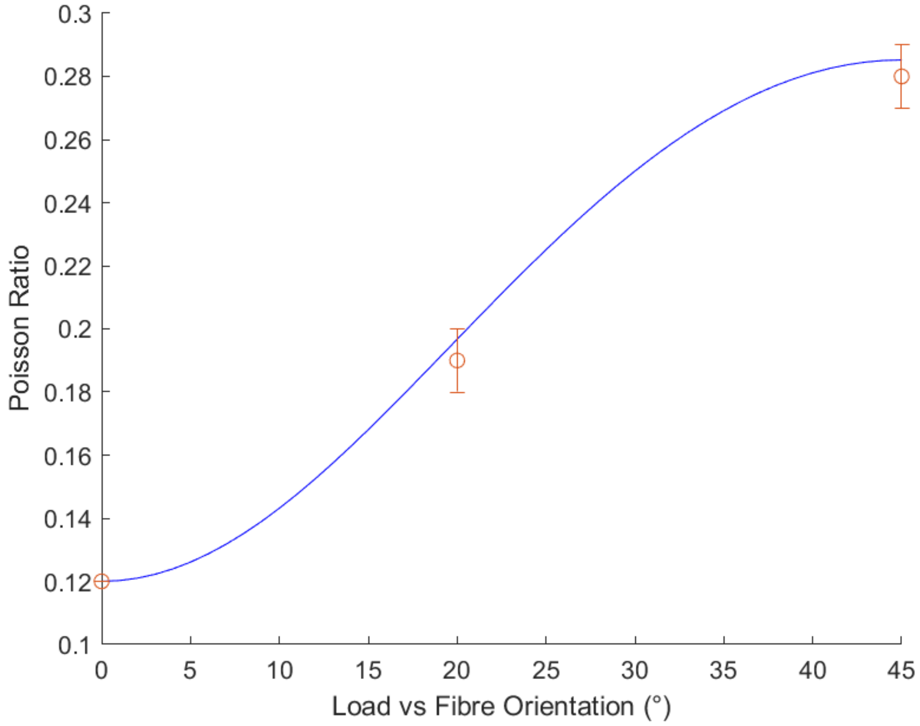
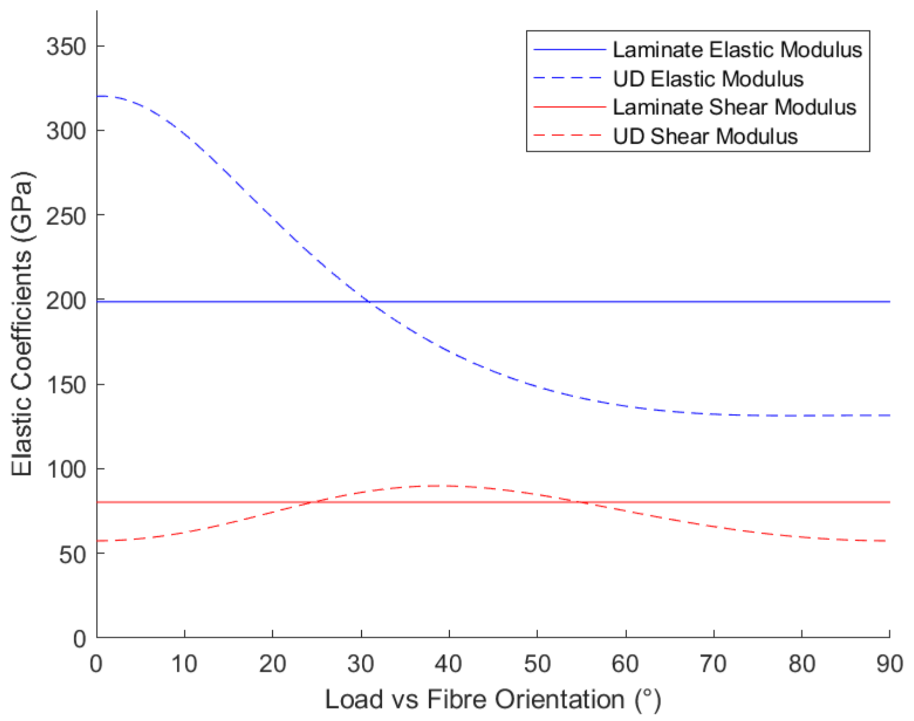


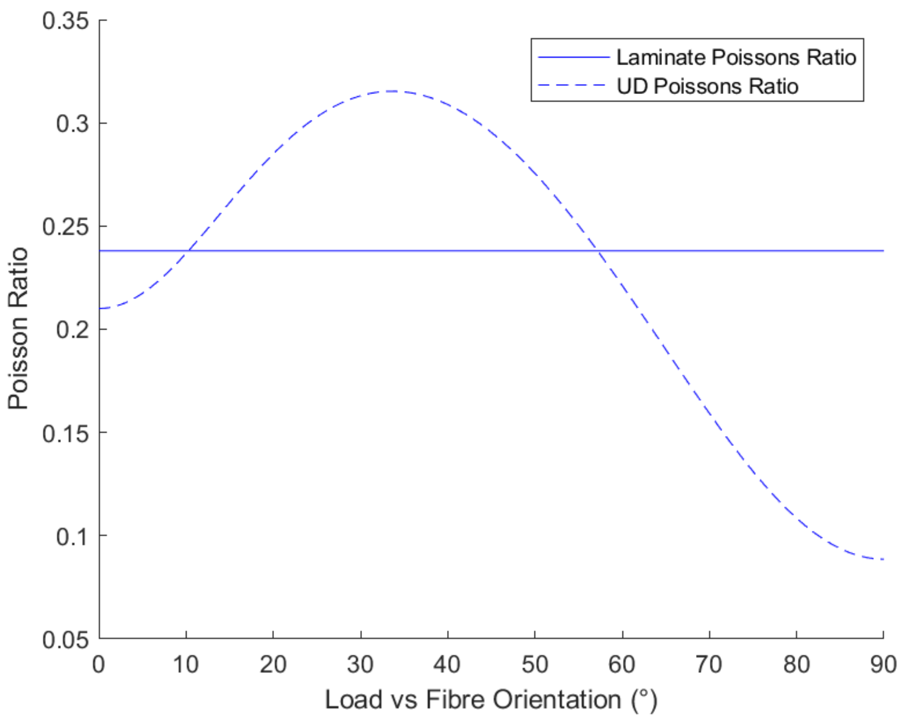
Overall, there is **good agreement** between the model and the experimental data, with the largest deviation between the two being 6.24%.

02 Anisotropy Characterization of SiC_f/SiC Laminates

Implications to Blanket Design

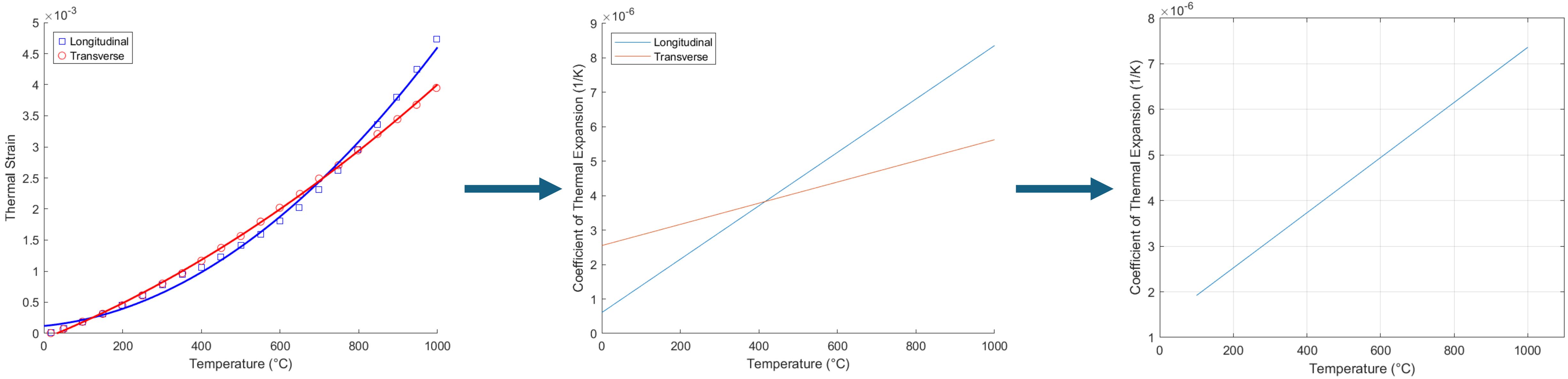
CLT has proven to **accurately predict** the behaviour of SiC_f/SiC composites and thus can be used to begin evaluating **potential layups to be used**. At this stage of development, utilising a material with isotropic material properties is useful to simplify analysis. This is possible with **quasi-isotropic layups** such as [0, +45, - 45, 90, 90, -45, +45, 0]. The figures below compare the results for this layup with a **UD composite**:





02 Anisotropy Characterization of SiC_f/SiC Laminates

The quasi-isotropic layups also create an **isotropic response** for coefficient of linear thermal expansion. Combining CLT with temperature thermal expansion data for longitudinal and transverse directions [2], allow for temperature dependent, **homogenised thermal expansion coefficients** to be found:



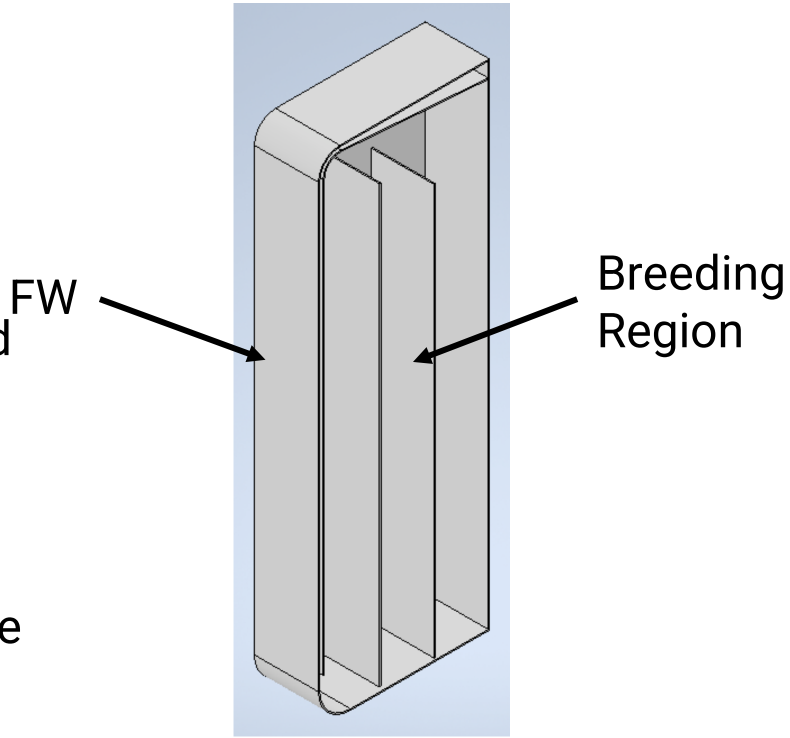
[2] Hollenberg, G. W., C.H. Henager, G. E. Youngblood, D. J. Trimble, S. A. Simonsen, G. A. Newsome, and E. Lewis. 1995. "The Effect of Irradiation on the Stability and Properties of Monolithic Silicon Carbide and SiCf/SiC Composites up to 25 dpa," J. Nucl. Mat., 219: 70–86.

03 Structural Optimization of Blanket Modules

As part of the **preliminary thermo-mechanical analysis** of the module designed during SCS – Phase 1, extremely **high stresses were found** (~ 9 GPa). These were primarily driven by **hydrostatic forces** (such as the operating pressure of the module), with the exception of the first wall (FW), where **thermal stresses** began to have a relevant contribution to the total stress.

In this section, a method for quantifying the number of supporting ribs in the breeder region to **reduce the stress to acceptable level** is presented. For the FW, an arched geometry is suggested and a method for sizing the arches is provided. For this analysis, a simplified "box" version of the SCYLLA blanket module is used.

The goal of this analysis is to **generate generalised tools** that could be applied to any blanket geometry or concept under **hydrostatic loads**. The tools should help avoid these extremely large stresses, allowing identification of an **initial design** with a **reasonable stress distribution**, which can then be further optimized based on more detailed analysis **including the effect of all other loads** such as MHD forces.



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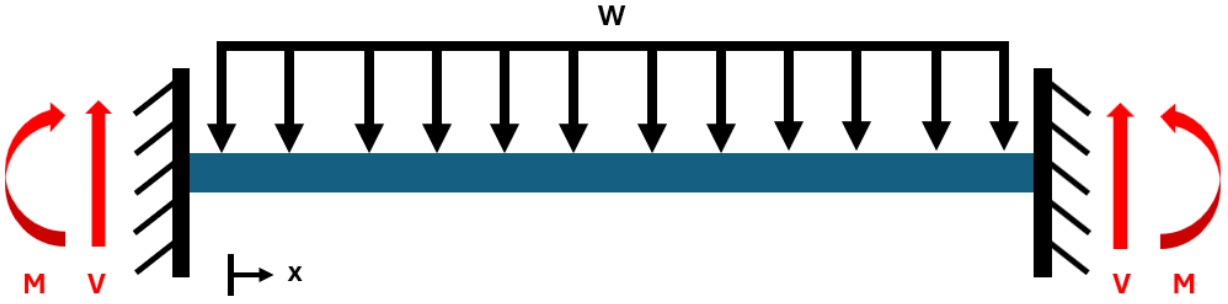
Breeding Region Optimisation

The module's response to hydrostatic loads can be approximated as a **beam bending problem**, with double cantilever end constraints and a uniformly distributed load:



$$\sigma = -\frac{My}{I}, I = \frac{Ht^3}{12}, M = \frac{W}{12}(6Lx - 6x^2 - L^2), W = P \cdot H$$

Parameter	Unit	Value
Operating pressure, P	Pa	1.88e6
Panel height, H	m	2.325
Panel width, L	m	0.66
Wall thickness, t	m	0.003

The maximum stress occurs at $x = 0$, and $y = {}^{t}/_{2}$:

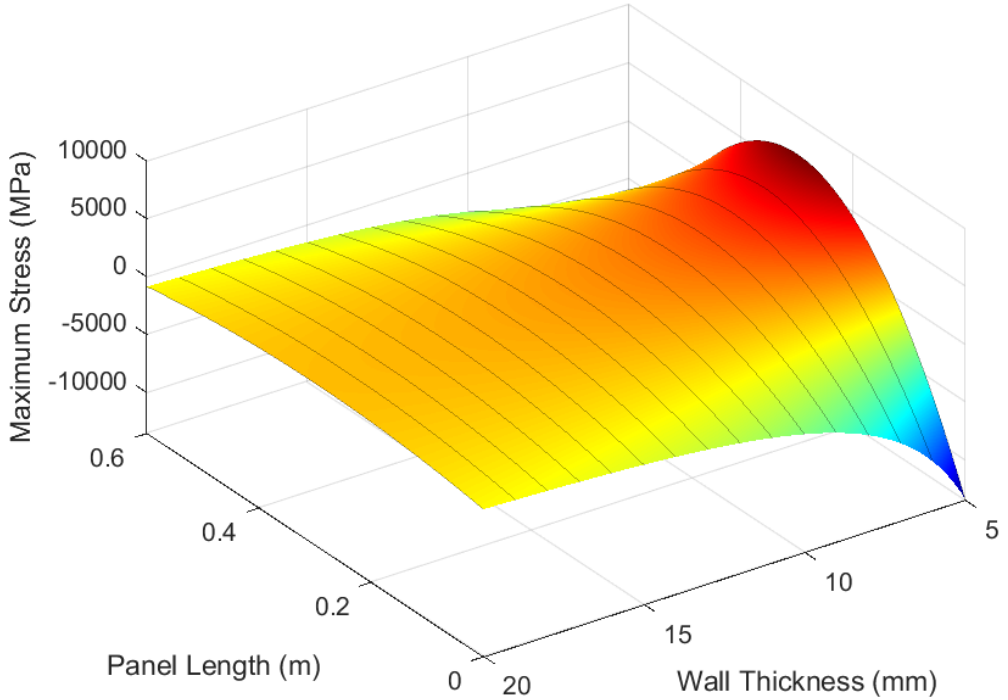
$$\therefore |\sigma| = \frac{PL^2}{2t^2}$$

This shows that there are **two fundamental ways to reduce the stress**: reduce the effective **width** of the panel or increase the panel **thickness**.

03 Structural Optimisation of Blanket Modules

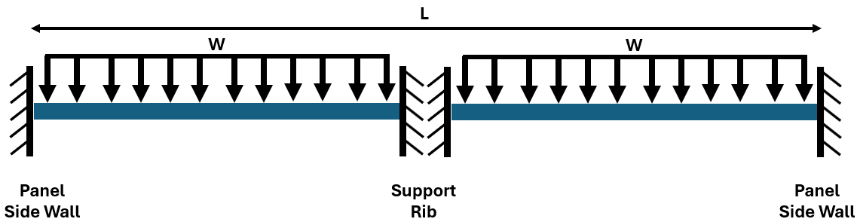
Increase t:

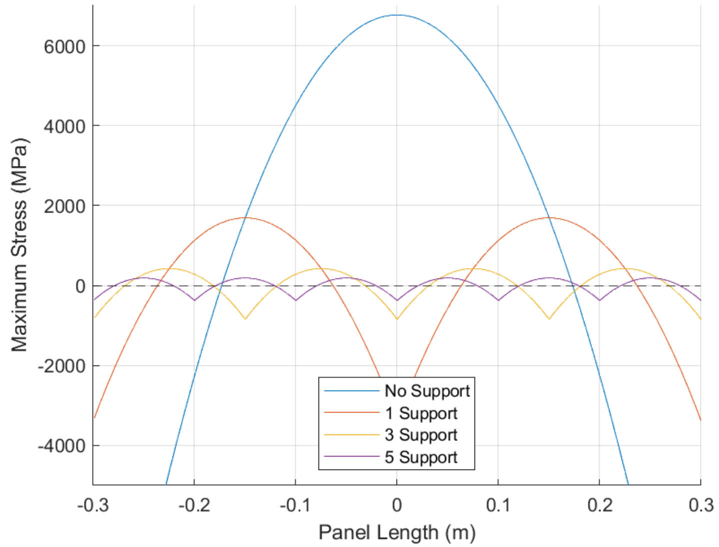
Increasing **wall thickness** is easily achieved but adding more layers to the composite would require very thick walls.



Decrease effective L:

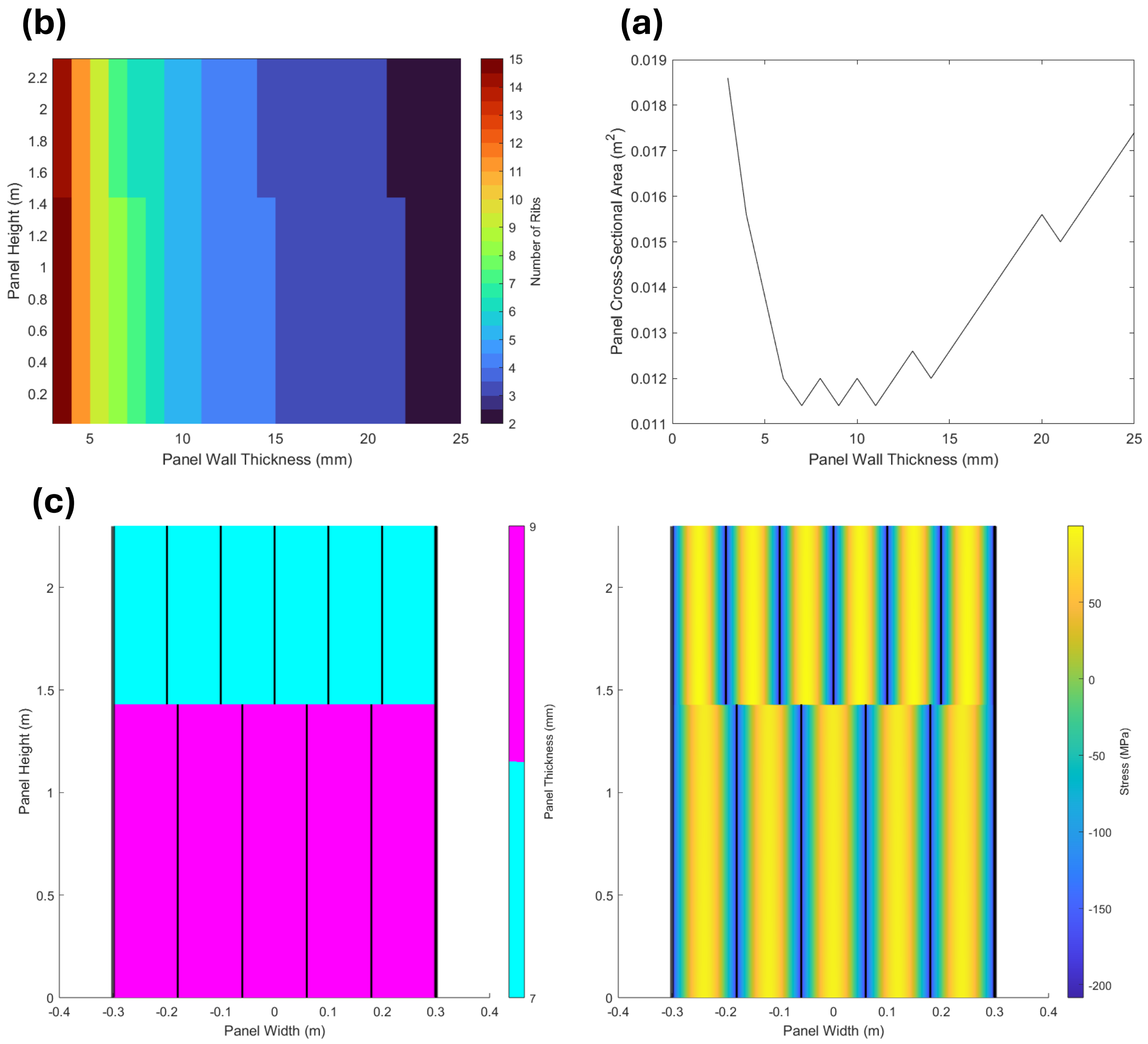
Can be achieved by adding **support ribs**, essentially halving the effective length with each additional rib.





03 Structural Optimisation of Blanket Modules

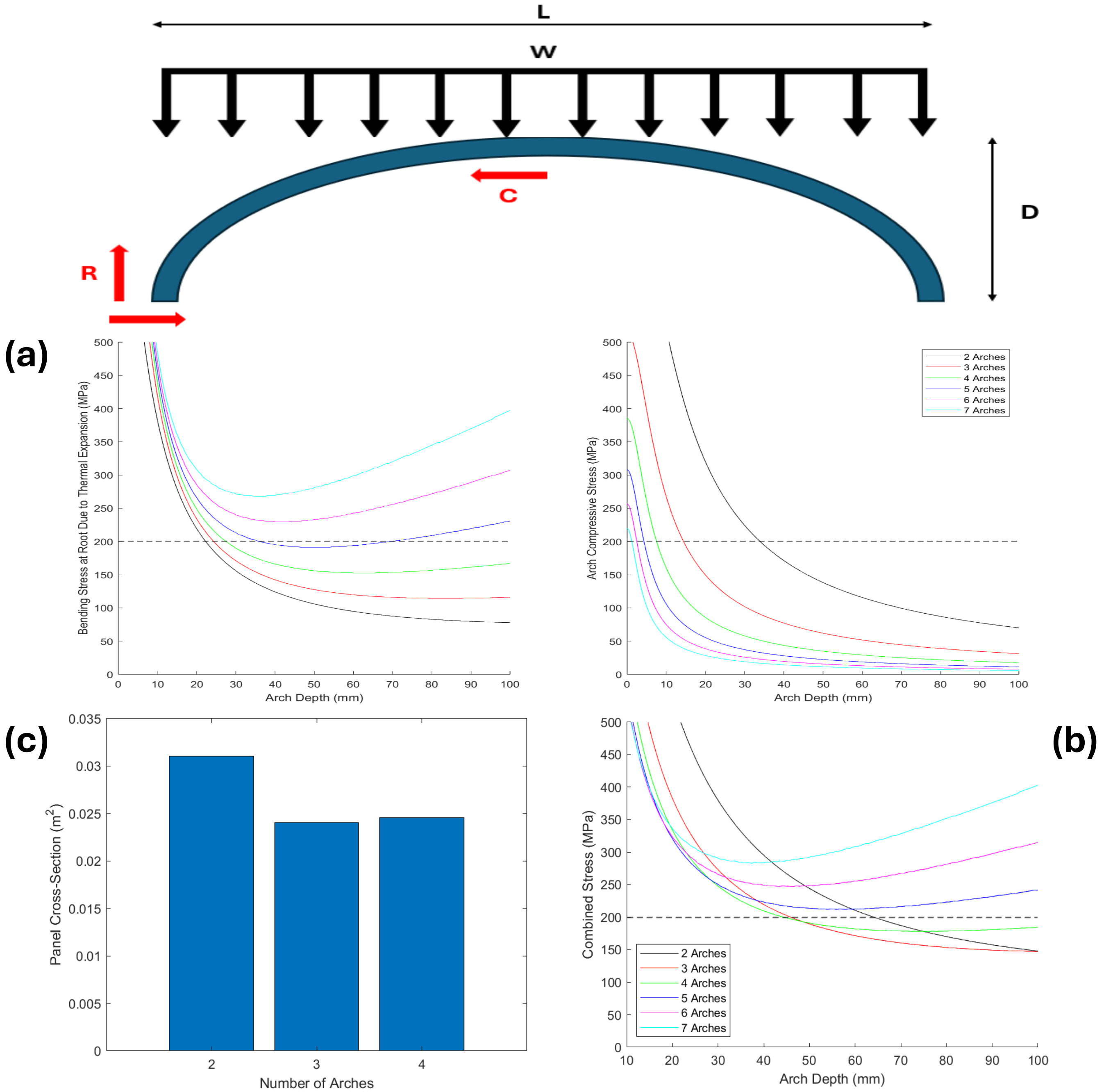
- The most efficient structure **minimises the SiC_f/SiC volume.** This requires a trade-off between the module wall thickness and the number of ribs, in order to **minimise cross-sectional area (a)**.
- Additionally, the **pressure varies along the height of the module**, meaning this trade-off must be made along the whole height of the module **(b)**.
- Performing the **optimisation** approach shown in **(a)**, along the height of the panel allows for a **schematic of the panel** to be generated **(c).**



03 Structural Optimisation of Blanket Modules

First Wall Optimisation

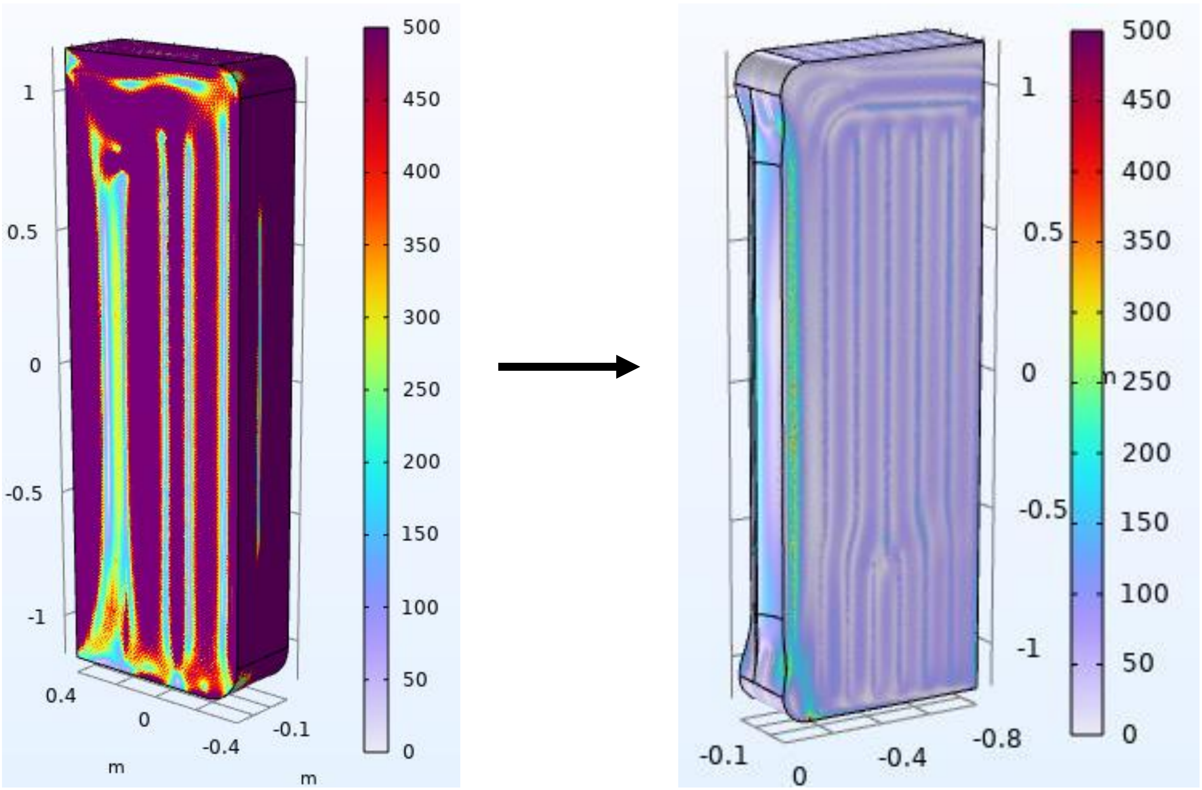
- The SiC_f/SiC first wall should be **as thin as possible** to help in reducing thermal stresses. 3mm has been assumed for this analysis
- **Arched structures** place the SiC_f/SiC under compression when exposed to **pressure loads**.
- At **elevated temperatures,** the depth of the arch increases, leading to a **decrease** in pressure related stresses.
- Temperature-related deformation causes stresses at arch roots.
- A **trade-off** exists between thermal and pressure-based stresses **(a).** To select the appropriate configuration these stresses are combined **(b).**
- Once again, the **minimum cross-sectional area** option is selected **(c)**.
- FW design is an on-going process and will be iterated according to new plasma data from UKAEA.



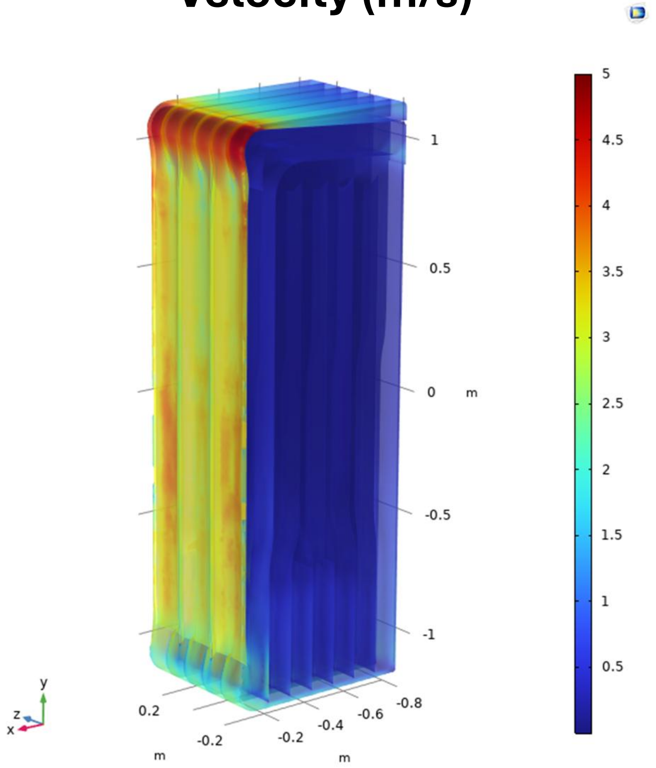
03 Structural Optimisation of Blanket Modules

- Optimisation was performed for each panel making up the breeding blanket.
- Optimisation for the first wall is in progress.
- The change in geometry resulted in a **7.28%** reduction in LiPb volume .
- KF is currently finalising the design and completing TM analyses.

Pressure Related Stress @ 800 K (MPa)



Velocity (m/s)

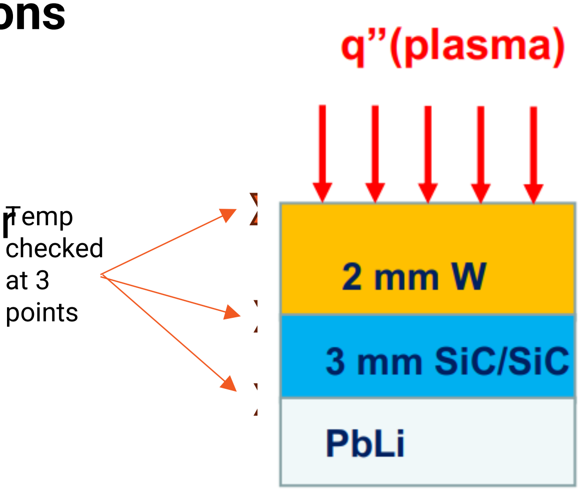


04

Transient Thermal Analysis under Disruption Events

A new study to evaluate the impact of disruptions

- **RACLETTE**: Rate Analysis Code for pLasma Energy Transfer Transient Evaluation [3].
- In collaboration with original RACLETTE author R. Raffray
- UKAEA input parameters on heat loads used.
- The study used the RACLETTE code to estimate the **evolution of temperatures** and **evaporation rates** from a disruption based on the following example parameters.



Parameter	Unit	Value
Initial W armour thickness	mm	0.5 to 3
SiC_f/SiC thickness	mm	3
Heat transfer coefficient, HTC (LiPb coolant)	$W/(m^2 K)$	2000 to 5000
Plasma q” prior to transient	MW/m^2	0.7
Transient energy deposition	GW/m^2	2.2 over 1 ms
LiPb temperature	° C	500 to 700
Peaking factor for 1D to 2D analysis	-	1.2

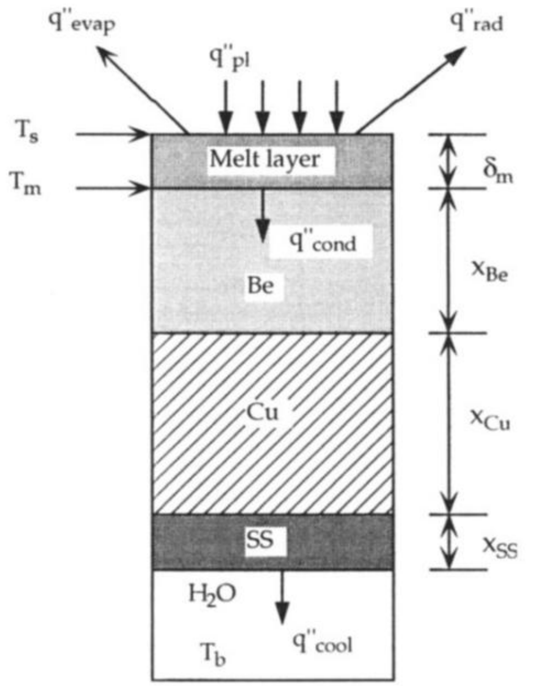


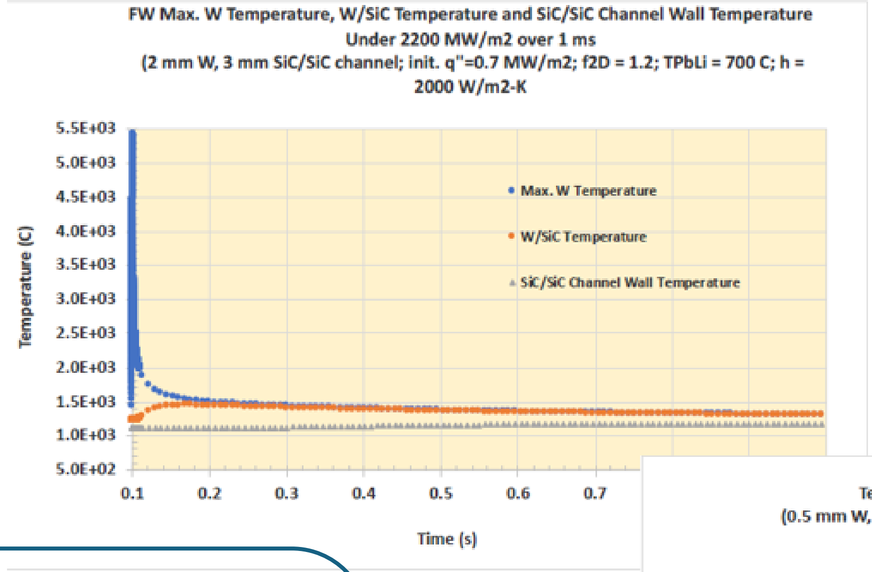
Fig. 1. Simple conduction model for transient analysis of plasma energy deposition on plasma facing surface including effect of melt layer, evaporation and radiation.

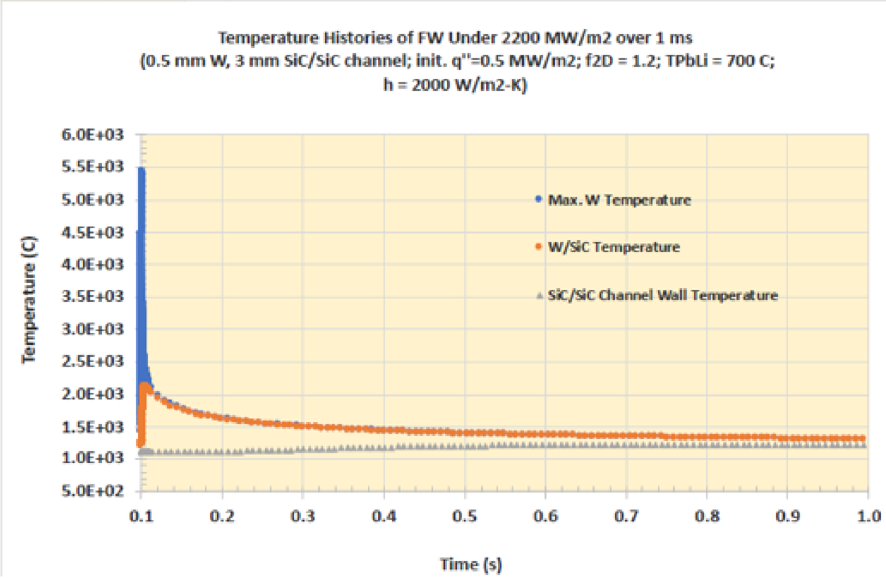
[3] A.R. Raffray and G. Federici, “RACLETTE: a model for evaluating the thermal response of plasma facing components to slow high power plasma transients. Part I: Theory and description of model capabilities,” Journal o[Nuclear Materials 244 (1997) 85-100 .

04 Transient Thermal Analysis under an Assumed Disruption Event

- Parametric analyses are useful in determining the effect of changing a number of different parameters, such as the **armor thickness**, the **LiPb temperature** and the **LiPb heat transfer coefficient**.

- For example, the two figures here show the **temperature histories** at the W surface, at the interface of W and SiC_f/SiC, and at the SiC_f/SiC channel wall for cases with 2 mm thick W and 0.5 mm thick W, respectively.





- Not much difference in maximum W temperature; and some modest difference in maximum LiPb/SiC temperature.
- However, substantial difference in maximum SiC/W interface temperature, which is likely to be the governing limit in such cases.
- Its impact is presented in more details in the next slide.

04 Transient Thermal Analysis to Determine Effect of Changing Various Parameters

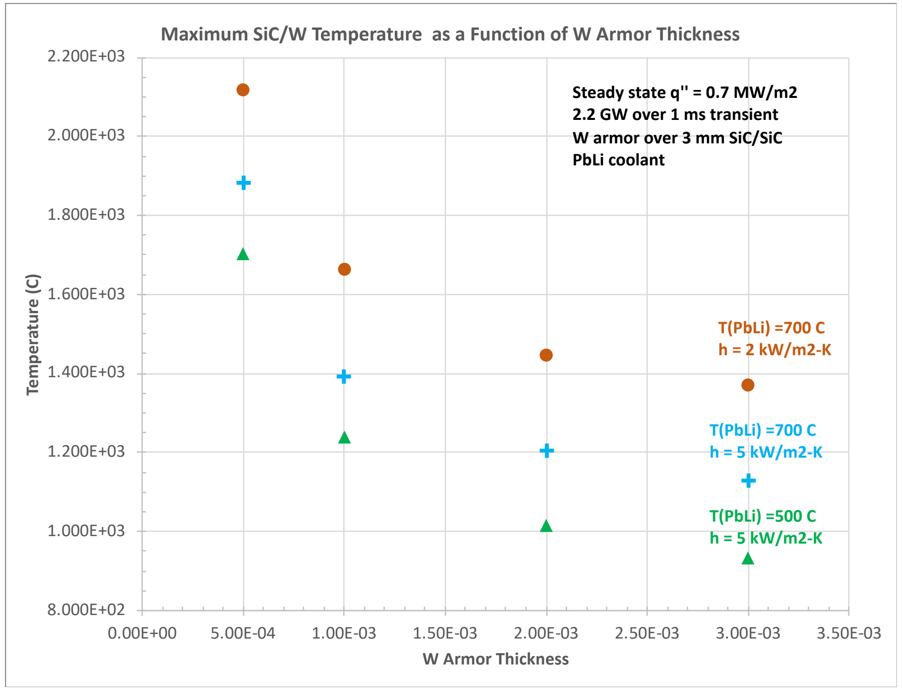
- The figure shows the **maximum SiC/W interface temperature** following the assumed disruption event as a function of the W armor thickness for different assumed LiPb temperatures and LiPb HTC's at the SiC_f/SiC channel wall.

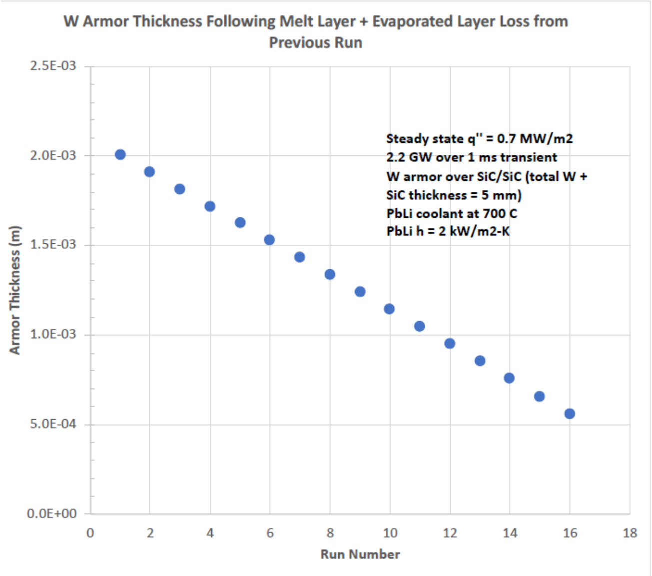
- The maximum temperature at the interface of W and SiC_f/SiC **increases substantially with decreasing thickness** in all cases and will be the parameter setting the number of such events that a particular spot can handle.

- For example, if the **maximum temperature limit** is assumed to be about **1000 °C** for SiC_f/SiC, the only possibility for the cases analyzed is having a LiPb temperature of 500 C, HTC of 5 kW/m^2-K and an armor thickness of 2 mm or more (only one or two such transient events would be acceptable for 2 mm W, and more for a thicker armor). A higher SiC_f/SiC temperature limit **would be very beneficial** in providing a better possibility of accommodating more disruption events.

- For interest, a number of runs were made to provide a rough estimate of the **decrease in W armor thickness** following a series of such disruption events by adjusting the W armor thickness based on the evaporated and complete melting layer armor lost from the previous run.

- It takes about **16-17 runs** for the armor thickness to decrease **from 2 to 0.5 mm**.





05 Conclusion and Future Work

1. **SCYLLA concept & development path are defined and actionable**: a SiC_f/SiC + LiPb self-cooled blanket aimed at low-stress operation, supported by manufacturing R&D, maintainability, and integrated testing in UNITY-1 and MHD mock-ups, now transitioning from SCS Phase 1 to a Phase 2 focus on stress reduction.
2. **Anisotropy is under control via CLT**: Classical Laminate Theory accurately reproduces measured SiC_f/SiC properties (largest deviation ≈ 6.24%), enabling confident use of quasi-isotropic lay-ups for global analyses and temperature-dependent homogenised CTEs.
3. **Structural strategies markedly lower stresses**: beam-bending-based sizing of breeder-region ribs (reducing effective panel width) provide design rules to keep combined stresses near an acceptable ~200 MPa level.
4. **Disruption transients set practical thermal limits**: Example RACLETTE analyses show that temperatures and in particular SiC/W interface temperature are sensitive to HTC and LiPb bulk temperature; armour erosion scenarios converge towards thin W layers, while the SiC_f/SiC temperature limit constrains the minimum W thickness (for a limit of <~1000-1100°C, cases with 700°C LiPb and low HTC may be unacceptable).
5. **Design trade-offs are explicit**: optimisation reduces peak stresses but also the LiPb volume (~7.28% for the example case analysed), so recovering TBR will require coupled thermo-mechanical-neutronic iterations, FW design, targeted material/geometry choices.

Thank you for your attention!
ご清聴ありがとうございました!

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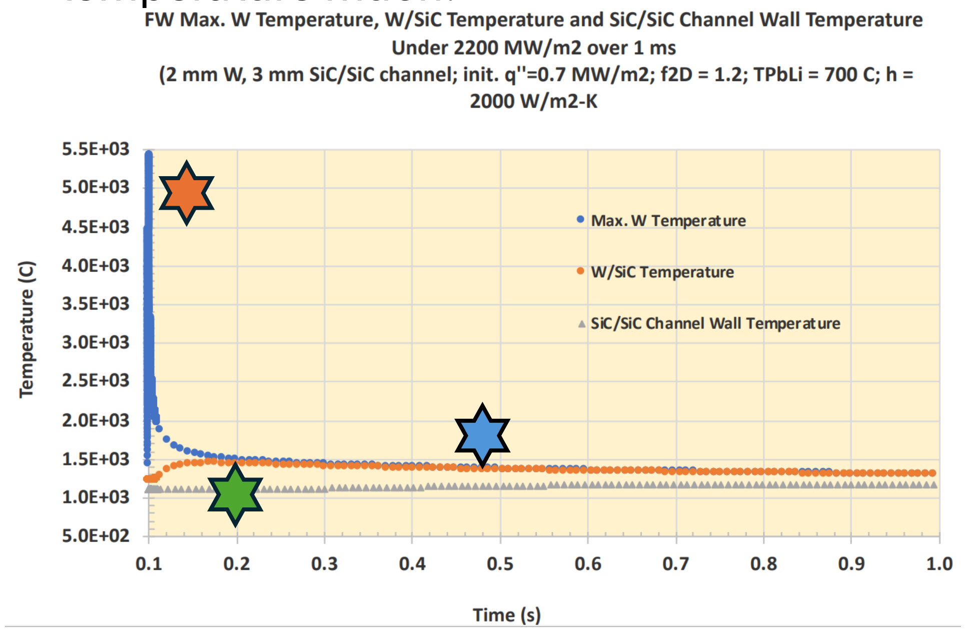
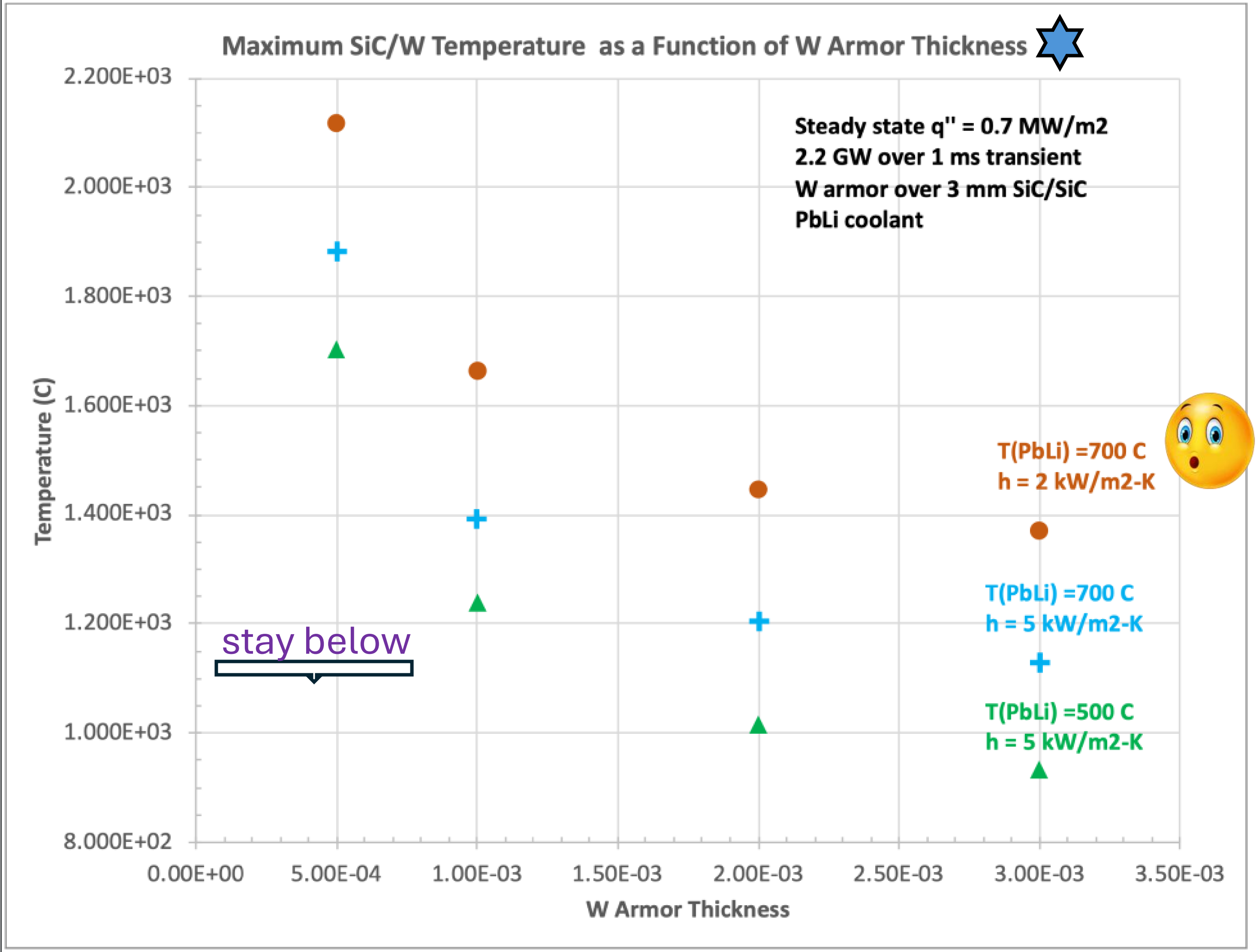
Back-up Slides

04 Transient Thermal Analysis under Disruption Events

- A higher SiC_f/SiC temp limit is needed, at least 1100 °C
- Issue when HTC is low and LiPb temp is high (current design just below 700 °C)
- LiPb temperature is restricted by irradiation swelling (500 °C needs to be checked).
- More than 3 mm could lead to issues with strength (is being checked) and more than 4 mm is not expected to influence temperature much.





BS Anisotropy Characterization of SiCf/SiC Laminates

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First, a relationship between stresses and strains in the principal directions for an individual lamina must be determined:

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{bmatrix} = \begin{bmatrix}Q_{11} & Q_{12} & 0\\ Q_{12} & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{bmatrix}$$

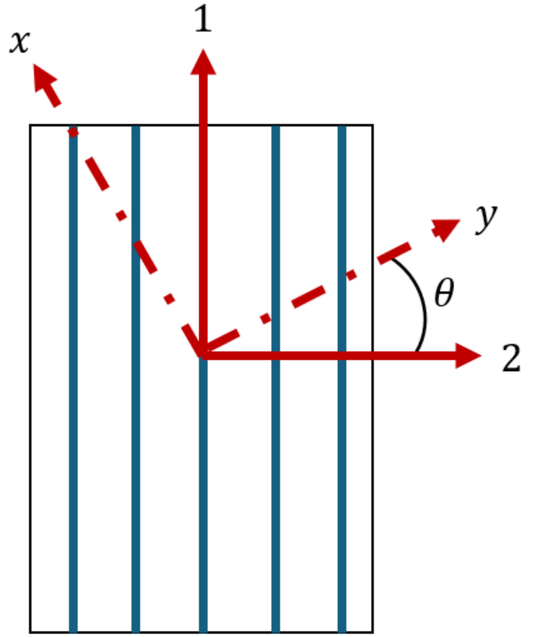
where:

$$Q_{11} = \frac{E_1}{1-\nu_{12}\nu_{21}}$$

$$Q_{22} = \frac{E_2}{1-\nu_{12}\nu_{21}}$$

$$Q_{12} = \frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}}$$

$$Q_{66} = G_{12}$$



These stresses and strains can be transformed to any arbitrary direction with the following equation:

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix} = \begin{bmatrix}cos^2\theta & sin^2\theta & -2sin\theta cos\theta\\ sin^2\theta & cos^2\theta & 2sin\theta cos\theta\\ sin\theta cos\theta & -sin\theta cos\theta & (cos^2\theta - sin^2\theta)\end{bmatrix}\begin{bmatrix}Q_{11} & Q_{12} & 0\\ Q_{12} & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{bmatrix}\begin{bmatrix}cos^2\theta & sin^2\theta & 2sin\theta cos\theta\\ sin^2\theta & cos^2\theta & -2sin\theta cos\theta\\ -sin\theta cos\theta & sin\theta cos\theta & (cos^2\theta - sin^2\theta)\end{bmatrix}\begin{bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{bmatrix}$$

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix} = \begin{bmatrix}\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16}\\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26}\\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{bmatrix}$$

BS Anisotropy Characterization of SiCf/SiC Laminates

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Once the $[\bar{Q}]$, or transformed stiffness matrix, has been created, the response for the entire laminate can be found by combining the constituent layers:

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}$$

$$A_{ij} = \sum_{k=1}^{n} \left[\bar{Q}_{ij}\right]_k t_k$$

where n is the number of laminas in composite, t is the lamina thickness, and i, j = (1, 2, 6) depending on which coefficient is being solved for. This allows the homogenised elastic constants of the composite to be found:

$$E_x = \frac{N_x}{h\varepsilon_x} = \frac{1}{h}\left(A_{11} + A_{12}\left(\frac{A_{26}A_{16} - A_{12}A_{66}}{A_{22}A_{66} - A_{26}^2}\right) + A_{16}\left(\frac{-A_{16}}{A_{66}} + \frac{A_{26}A_{12}A_{66} - A_{26}^2A_{16}}{A_{22}A_{66}^2 - A_{26}^2A_{66}}\right)\right)$$

$$E_y = \frac{N_y}{h\varepsilon_y} = \frac{1}{h}\left(A_{22} + A_{12}\left(\frac{A_{26}A_{16} - A_{12}A_{66}}{A_{11}A_{66} - A_{16}^2}\right) + A_{26}\left(\frac{-A_{26}}{A_{66}} + \frac{A_{16}A_{12}A_{66} - A_{16}^2A_{26}}{A_{11}A_{66}^2 - A_{16}^2A_{66}}\right)\right)$$

$$G_{xy} = \frac{N_{xy}}{h\gamma_{xy}} = \frac{1}{h}\left(A_{66} - \frac{A_{26}^2}{A_{22}} + \frac{2A_{12}A_{16}A_{26}A_{22} - A_{12}^2A_{26}^2 - A_{16}^2A_{22}^2}{A_{11}A_{22}^2 - A_{12}^2A_{22}}\right)$$

$$\nu_{xy} = \frac{-\varepsilon_y}{\varepsilon_x} = \frac{A_{12} - \frac{A_{16}A_{26}}{A_{66}}}{A_{22} - \frac{A_{26}^2}{A_{66}}}$$

where h is the thickness of the whole composite

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Coefficient of Linear Thermal Expansion

To find the homogenised linear thermal expansion coefficient in each direction, the resultant stress due to thermal expansion must be found:

$$\begin{bmatrix} N_x^T \\ N_y^T \\ N_{xy}^T \end{bmatrix} = \Delta T \sum_{k=1}^{n} \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix}_k \begin{bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{bmatrix}_k t_k$$

where

$$\begin{bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{bmatrix}_k = \begin{bmatrix} cos^2\theta & sin^2\theta & -2sin\theta cos\theta \\ sin^2\theta & cos^2\theta & 2sin\theta cos\theta \\ sin\theta cos\theta & -sin\theta cos\theta & cos^2\theta - sin^2\theta \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ 0 \end{bmatrix}$$

The above equations can be compared with $[A]$, or homogenised stiffness matrix, to solve for the homogenised linear thermal expansion coefficients:

$$\begin{bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{bmatrix} = \frac{1}{\Delta T} \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix}^{-1} \begin{bmatrix} N_x^T \\ N_y^T \\ N_{xy}^T \end{bmatrix}$$

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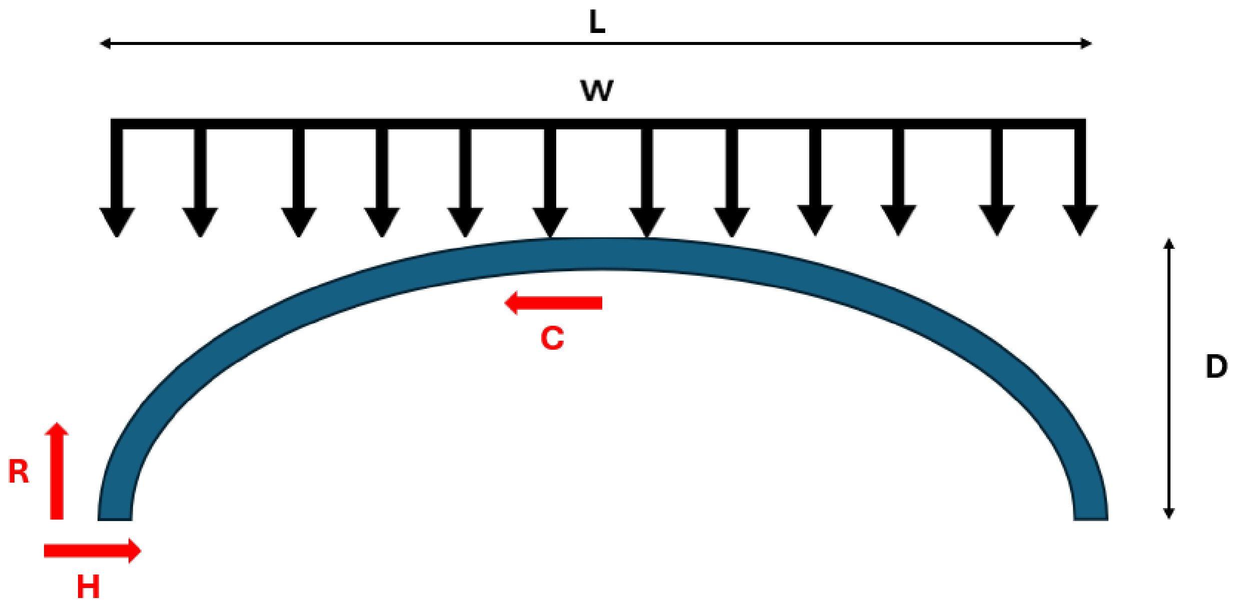
First Wall Optimisation

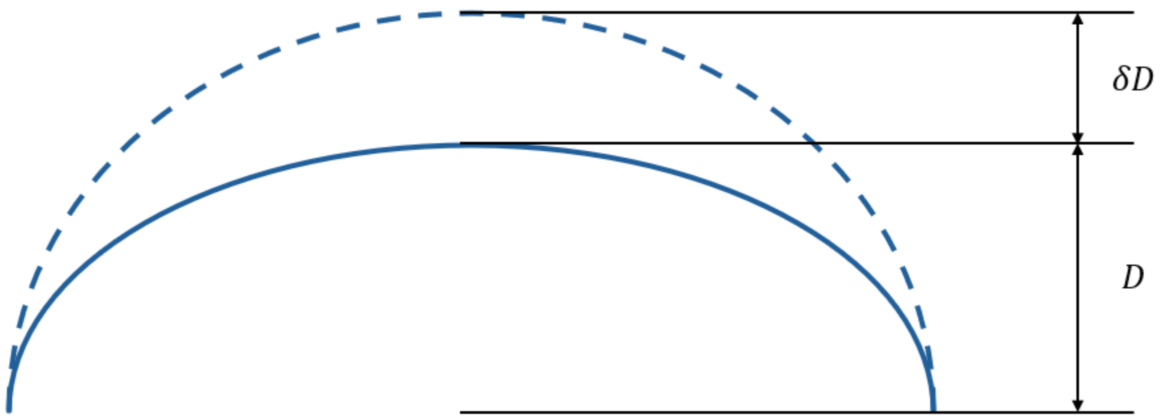
At the first wall, there is a desire to make the thickness of the SiCf/SiC as thin as possible to aide with cooling of the first wall. To aide in this, an arched structure for the first wall is suggested. Not only does this place the entire structure in compression, being very structurally efficient, but the increase in height of the arch when exposed to high temperature helps to further attenuate these pressure-based stresses:

$$R = \frac{WL}{2}$$

$$H = C = \frac{WL^2}{8(D + \delta D)}$$

$$\sigma = \frac{C}{A} = \frac{PHL^2}{8(D + \delta D)} \cdot \frac{1}{Ht} = \frac{PL^2}{8t(D + \delta D)}$$





03 Structural Optimisation of Blanket Modules

This increase in the depth of the arch under thermal loads, whilst beneficial for the pressure stresses, does generate stresses at the root due to the deformation. This deformation can be used to find the equivalent uniformly distributed load, and associated stress:

$$\delta D = \frac{WL^4}{384EI} \Rightarrow W = \frac{384\delta DEI}{L^4}$$

$$\sigma = \frac{16\delta DEt}{L^2}$$

This exposes a conflict between the two type of stresses, where the thermal stresses decrease with the square of the effective length and the compressive forces increase with the square of the effective length. To find the relationship between arch depth and δD the following equation must be solved:

$$(1 + \alpha\Delta T)\int_0^L \sqrt{1 + \left(\frac{4nD}{L_{panel}}\left(1 - \frac{2n}{L_{panel}}\right)\right)^2}\, dx = \int_0^L \sqrt{1 + \left(\frac{4n(D + \delta D)}{L_{panel}}\left(1 - \frac{2n}{L_{panel}}\right)\right)^2}\, dx$$

03 Structural Optimisation of Blanket Modules

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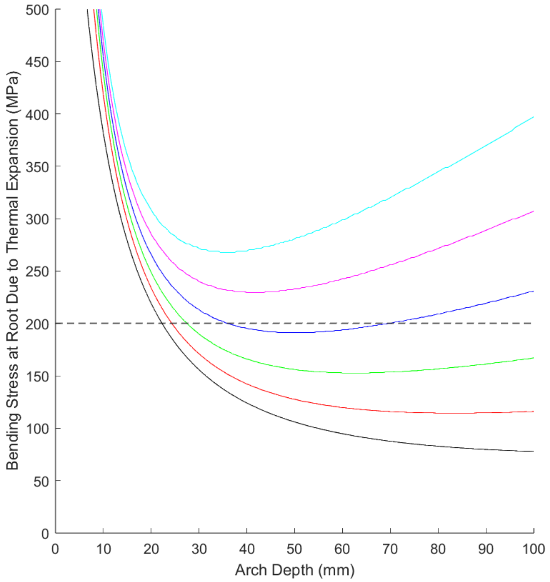
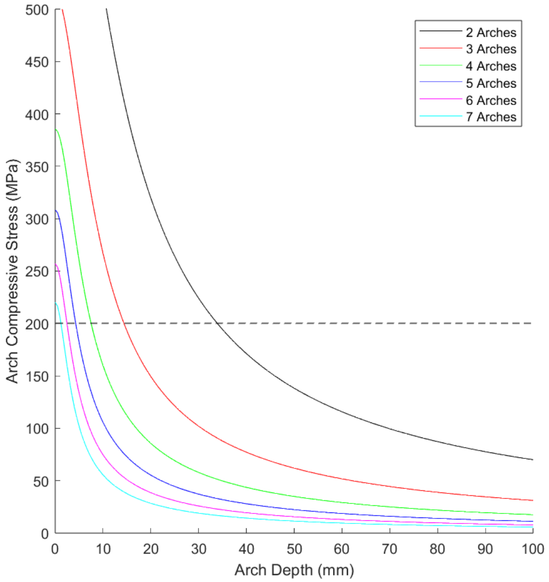
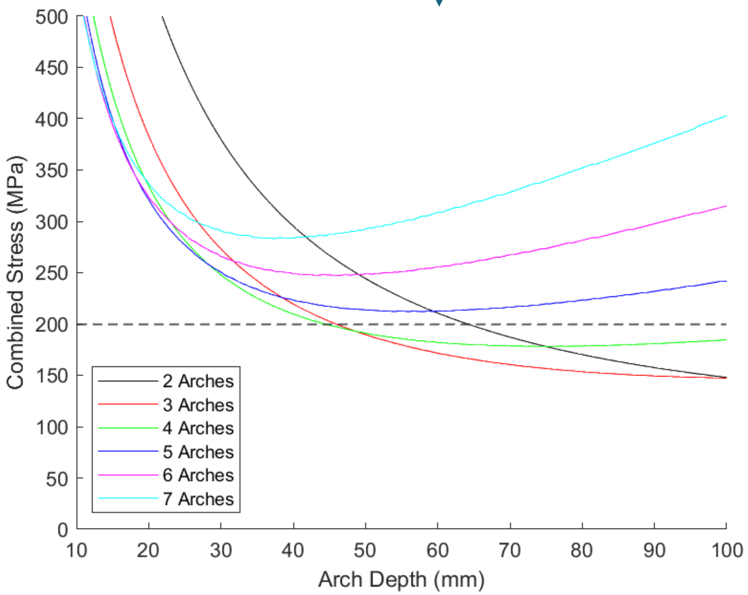
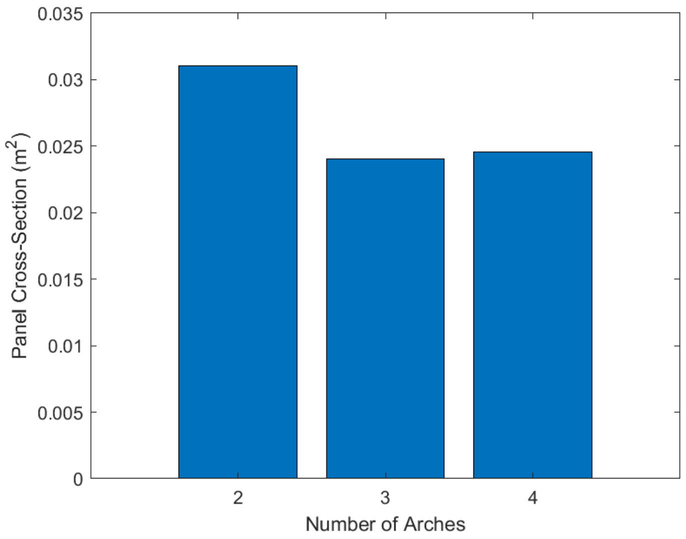
To ensure stresses in the final structure are acceptably low, it is assumed that the thermal and compressive stresses are combined.

Where this combined is below some stress limit (assumed 200 MPa in this case). The configuration with the least lost volume of LiPb is used.









03 Structural Optimisation of Blanket Modules

- Optimisation was performed for each panel making up the breeding blanket.
- Optimisation for the first wall is in progress.
- The change in geometry resulted in a **7.28%** reduction in LiPb volume