Variable Stiffness Composites for Morphing and Deployable Application

Henry C. H. Yu, Iman Mohagheghian and Paul A. Smith

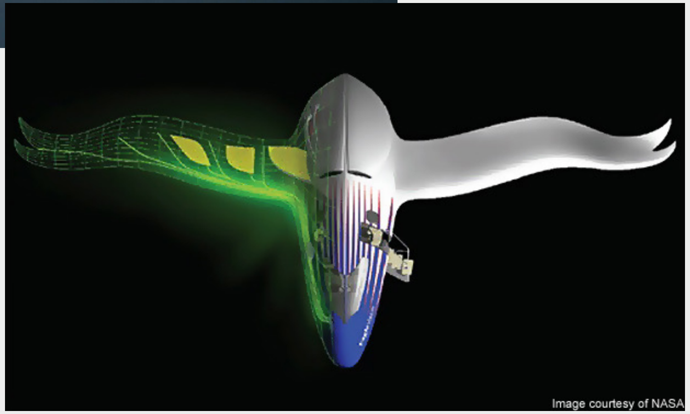
UNIVERSITY OF SURREY

Content

Introduction

» This research intends to investigate the concept of variable stiffness in laminated composite

» One main application of variable stiffness composites is in aerospace and space industries for deployable structures and morphing applications. Another application is in the emerging field of soft robotics



» **Variable stiffness** is the capability of altering the overall rigidity of a structure

» **Morphing** in engineering refers to continuous shape change upon activation in contrast to discrete parts moving relative to each other

NASA, digital image, accessed 14 May 2023, <https://shorturl.at/BCJPW>.
David Baillot / UC San Diego, digital image, accessed 14 May 2023, <https://shorturl.at/jkBM7>

Variable Stiffness Mechanism

- Variable Stiffness Mechanisms
  - Changing Geometry

    [Modify shape leading to a change in the second moment of area]
  - Altering Material Properties

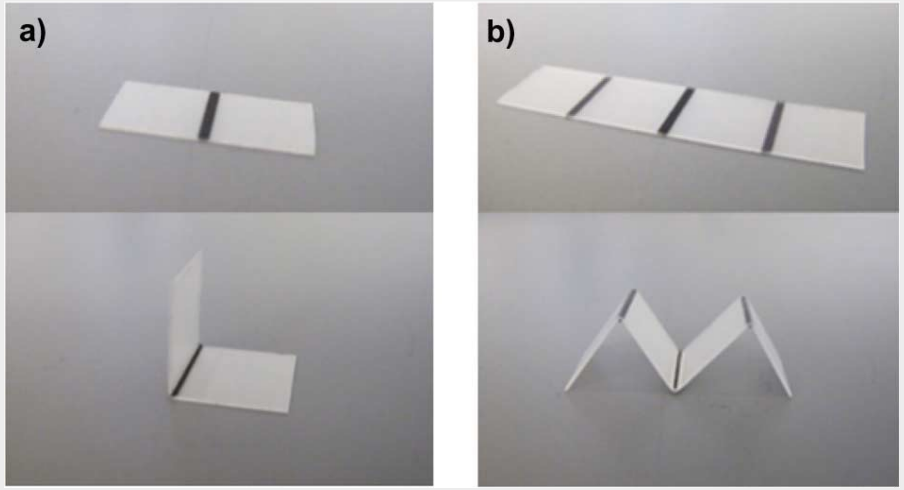
    [Variable stiffness enabled through stimulus]
  - Hybrid

    [Combination of the first two groups]

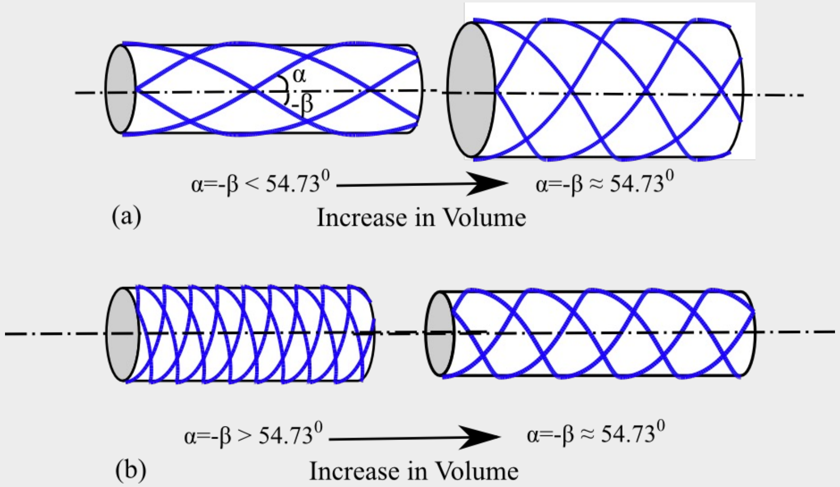
Kuder IK, Arrieta AF, Raither WE, Ermanni P. Variable stiffness material and structural concepts for morphing applications. Prog Aerospace Sci 2013;63:33-55

Variable Stiffness - Changing Geometry

» Modification of shape leading to a change in the second moment of area while having the material properties unchanged. (Hayes et. al., 2015) and (Krishnan et al., 2015)



(1)



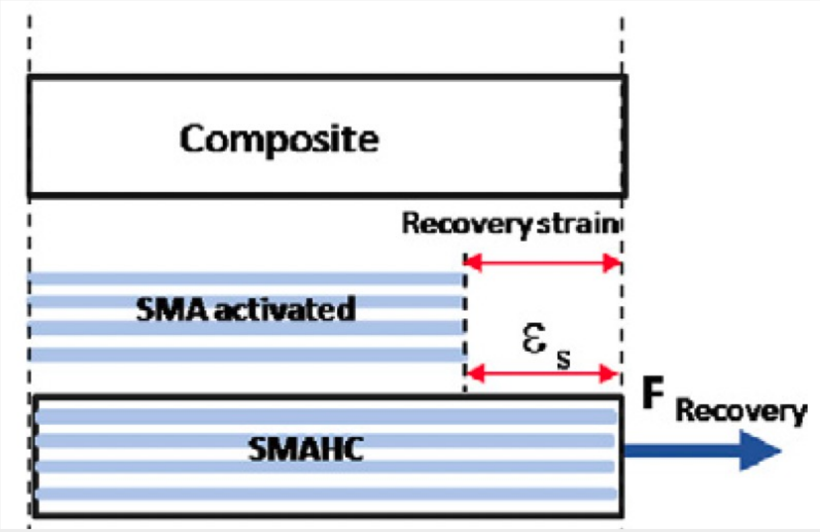
(2)

Figure. (1) The self-folding polymer sheet with multi hinges and (2) McKibben actuator with two families of fibres

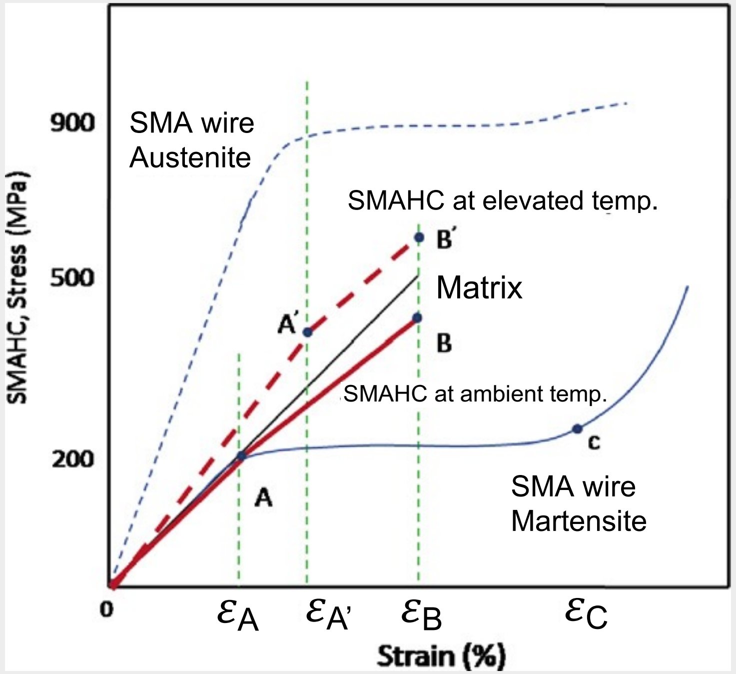
G.J. Hayes, Y. Liu, J. Genzer, G. Lazzi and M.D. Dickey, '"Self-folding origami microstrip antennas," IEEE Transactions on Antennas and Propagation, vol. 62, no. 10, pp. 5416-5419.
G. Krishnan, J. Bishop-Moser, C. Kim and S. Kota, '"Kinematics of a generalized class of pneumatic artificial muscles," Journal of Mechanisms and Robotics, vol. 7, no. 4, pp. 041014.

Variable Stiffness - Altering Material Properties

» Variable stiffness enabled by presence of SMA wires in a hybrid composite (SMAHC) plate. This can improve the overall structural response of the plate in terms of stiffness and strength at elevated temperatures



(1)



(2)

Figure. (1) Structure of a SMAHC plate and (2) stress–strain curve of the plate at ambient and elevated temperatures

Taheri-Behrooz F, Taheri F, Hosseinzadeh R. Characterization of a shape memory alloy hybrid composite plate subject to static loading. Mater Des 2011;32(5):2923-2933.

Variable Stiffness - Hybrid

» Utilise the benefits of both geometrical reconfiguration and altering material properties to achieve controllable stiffness in a structure

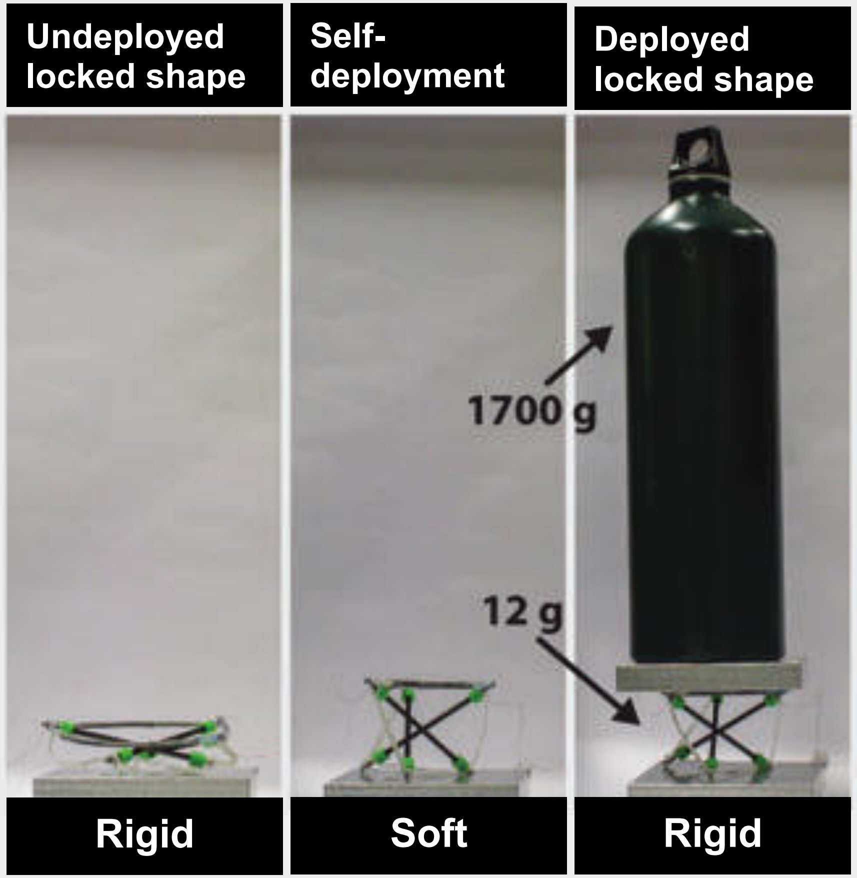


Figure. A structure that incorporates variable stiffness cables and a moveable structure to facilitate the change in structural stiffness. (Zappetti et al., 2020)

D. Zappetti, S.H. Jeong, J. Shintake and D. Floreano, '"Phase changing materials-based variable stiffness tensegrity structures," Soft robotics, vol. 7, no. 3, pp. 362-369.

Aim and Objectives

» Aim:

- To design and develop composite structures for morphing and deployable applications

» Objectives:

- To achieve a consistent laboratory manufacturing process for composite plates, incorporating the active layer
- To characterise the thermo-mechanical performance of these plates
- To characterise the electro-thermo-mechanical performance of these plates

Concept

- Variable Stiffness Mechanisms
  - Changing Geometry

    [Modify shape leading to a change in the second moment of area]
  - Altering Material Properties

    [Variable stiffness enabled through stimulus]
  - Hybrid

    [Combination of the first two groups]

» Applying a strategy of thermoplastic softening

» By combining two material systems with different T_g, a structure can be made in which the stiffness varies as a result of heating, either applied externally or generated internally

Concept

UNIVERSITY OF SURREY

Variable Stiffness Mechanisms

- Changing Geometry

  [Modify shape leading to a change in the second moment of area]

- Altering Material Properties

  [Variable stiffness enabled through stimulus]

- Hybrid

  [Combination of the first two groups]

» Applying a strategy of thermoplastic softening

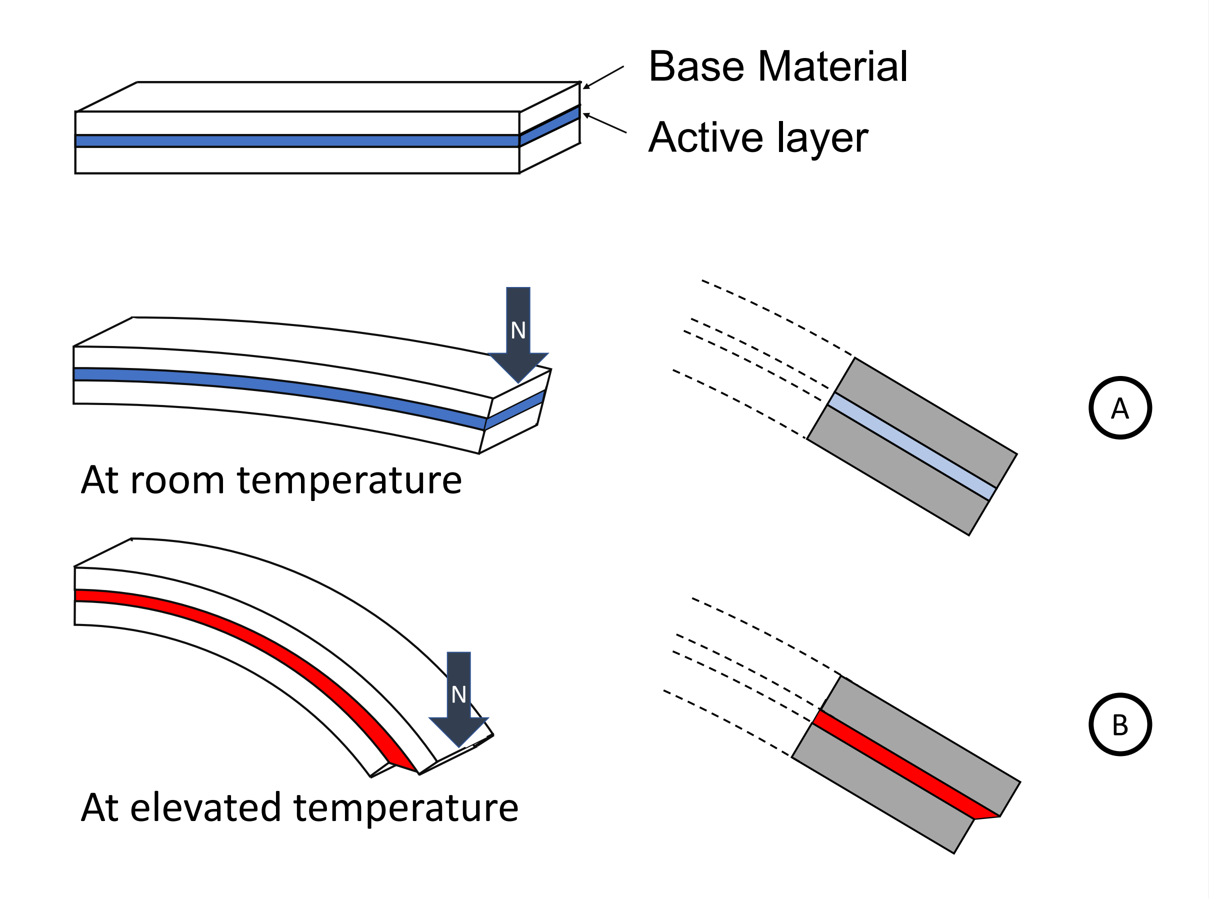
» By combining two material systems with different T_g, a structure can be made in which the stiffness varies as a result of heating, either applied externally or generated internally

Concept

- Interleaving thermoplastic layer (lower T_g) in a system with higher T_g

- The softening in the active layer will disrupt the shear stress transfer to the stacks and leading to stiffness reduction

A:	The structure is rigid below the active layer T_g
B:	It becomes compliant when the temperature is above the T_g of the active layer



Material Selection

Active layer material:

- The active material should not cause thermal degradation of the base material
- Softening effect occurs above room temperature
- The active material should be sufficiently stiff that it will not cause an excessive reduction in stiffness of the structure

Base Material:

- Stiff and light
- High T_g in comparison to the active layer
- Co-cured with the active layer

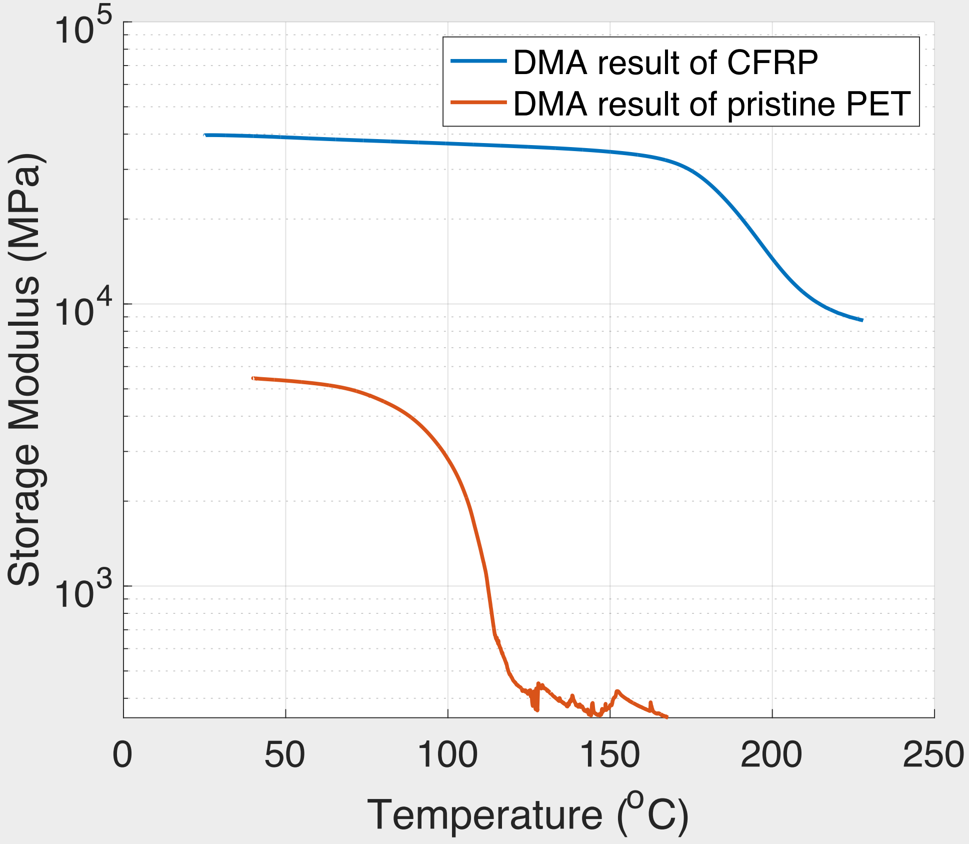
Material Selection

» Studied different thermoplastics in terms of T_g and modulus

» Finalised materials:

- **CFRP T_g at 170˚C (onset of *E'*)**
  - NTPT TP402/MR70 prepregs

- **PET T_g at 80˚C (onset of *E'*)**
  - GoodFellow Polyethylene Terephthalate (PET) Film



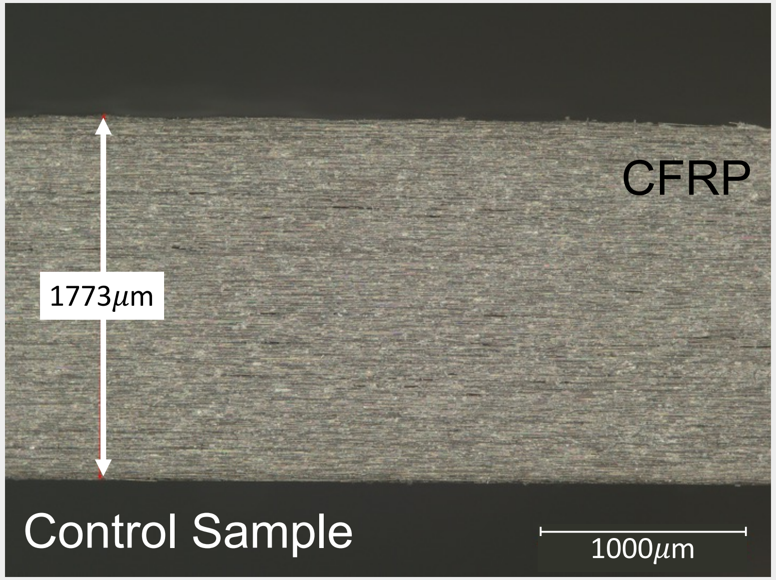
Manufacturing – Passive Heating Sample

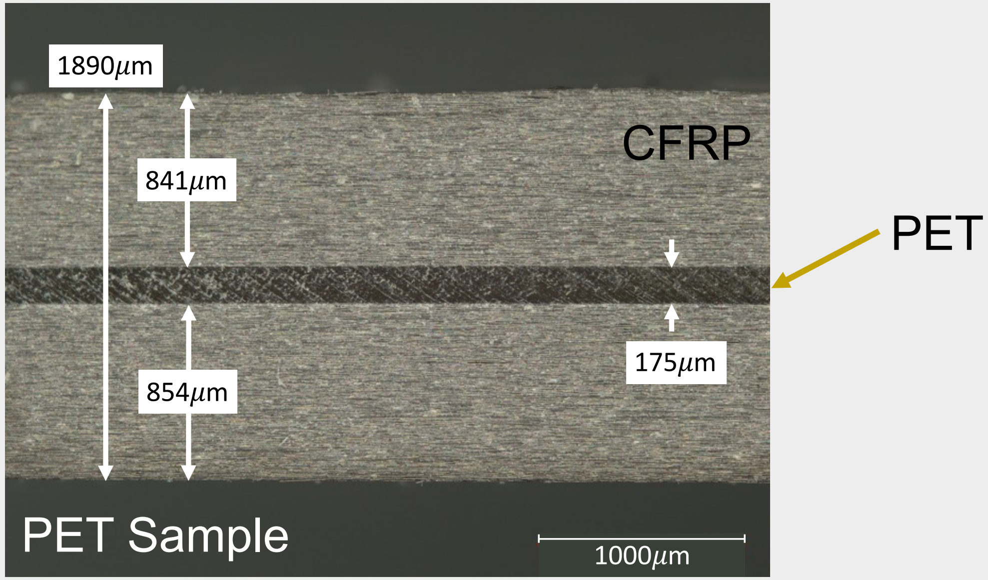
UNIVERSITY OF SURREY

» Hand layup and cure in the hot press at 6 bar

» Layup configuration:

- Control Sample: [0°_{60}]
- PET Sample: [0°_{30}/PET/ 0°_{30}]





Manufacturing – Active Heating Sample

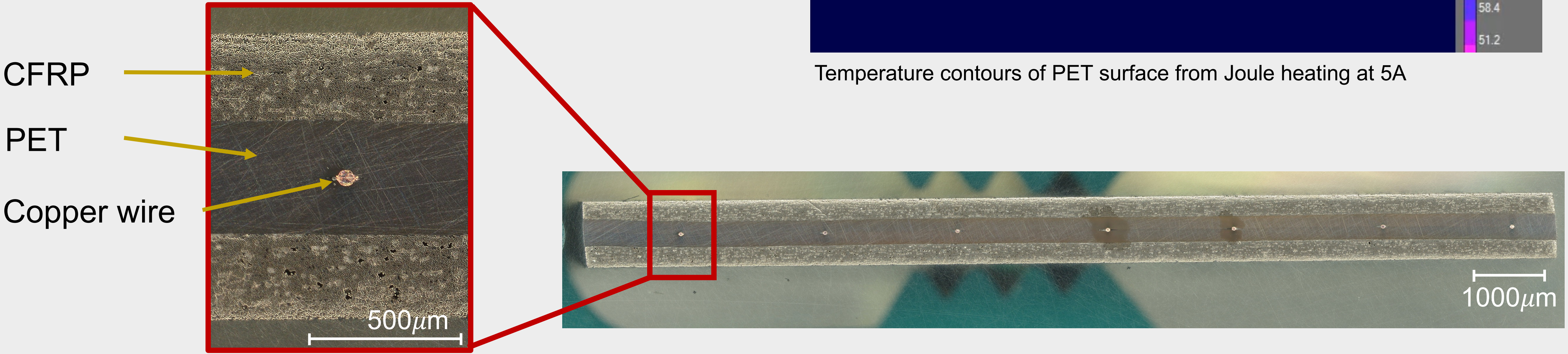
» 7 Copper wires were embedded between two layers of PET film

» Hand layup to assemble the stack which was cured in the hot press at 6 bar

» Layup configuration:

- [0°_{10} / PET / Copper wires / PET / 0°_{10}]

Temperature contours of PET surface from Joule heating at 5A

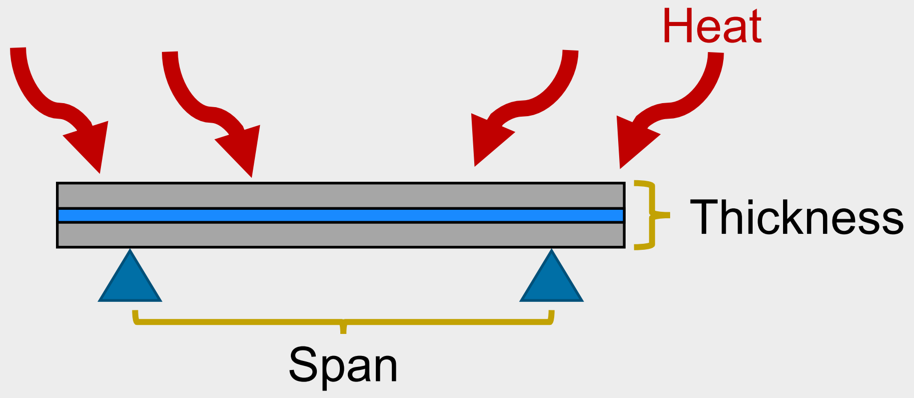


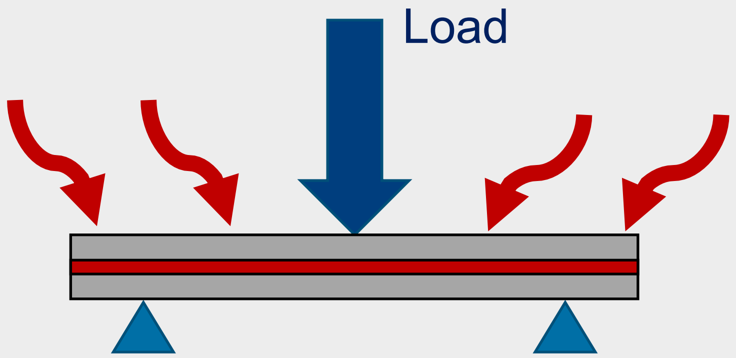
Testing – Passive Heating

» Three point bending test was used to obtain flexural stiffness

» Samples were heated in the environmental chamber and loaded once the target temperature was reached

» For both control and PET samples, the span-to-thickness ratio remained the same



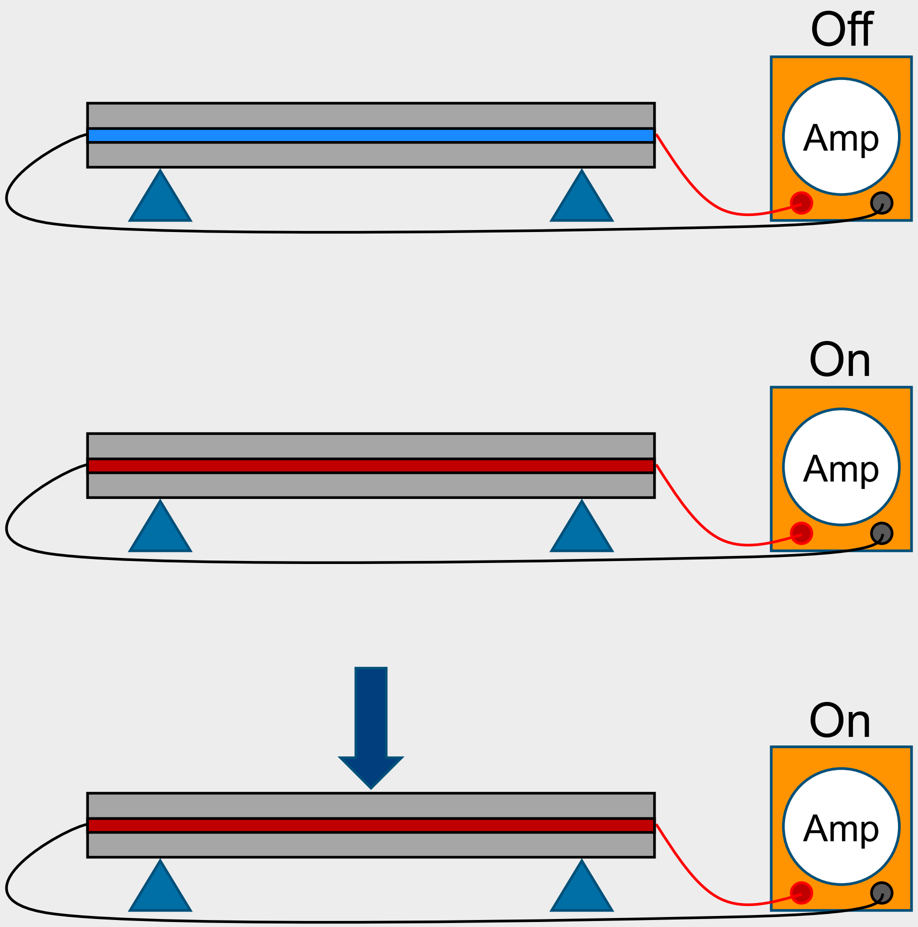


Testing – Active Heating

» To actuate the active interlayer, a constant current was applied using Joule heating

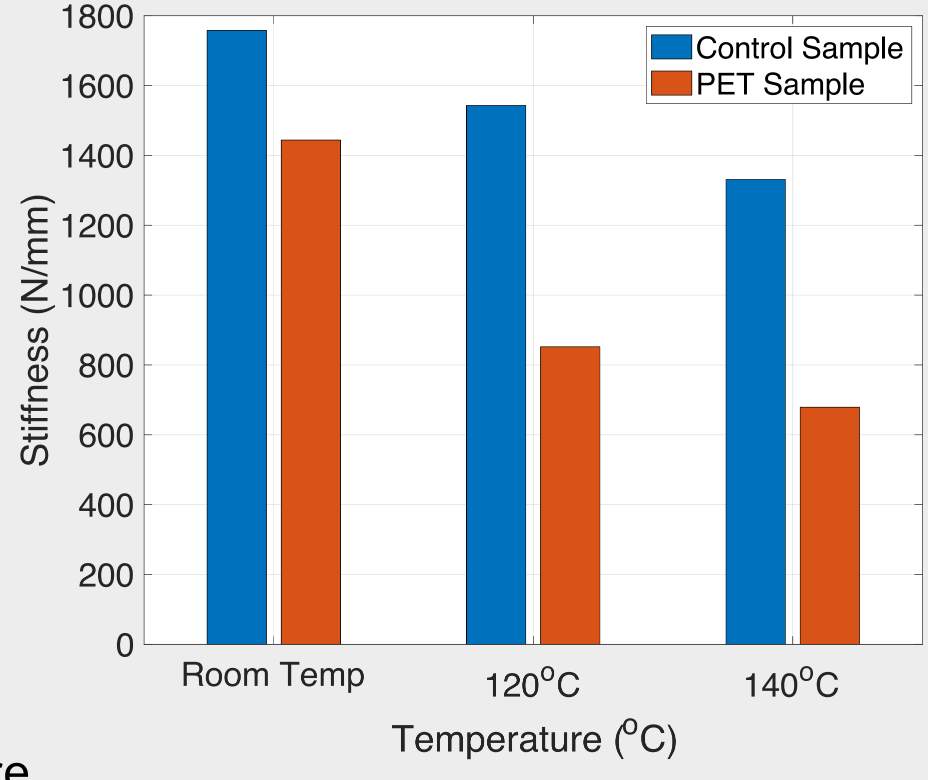
» Samples were pre-heated using a range of current and time of heating

» Samples were then loaded to obtain the flexural stiffness from three point bending test



Result and Discussion – Passive Heating

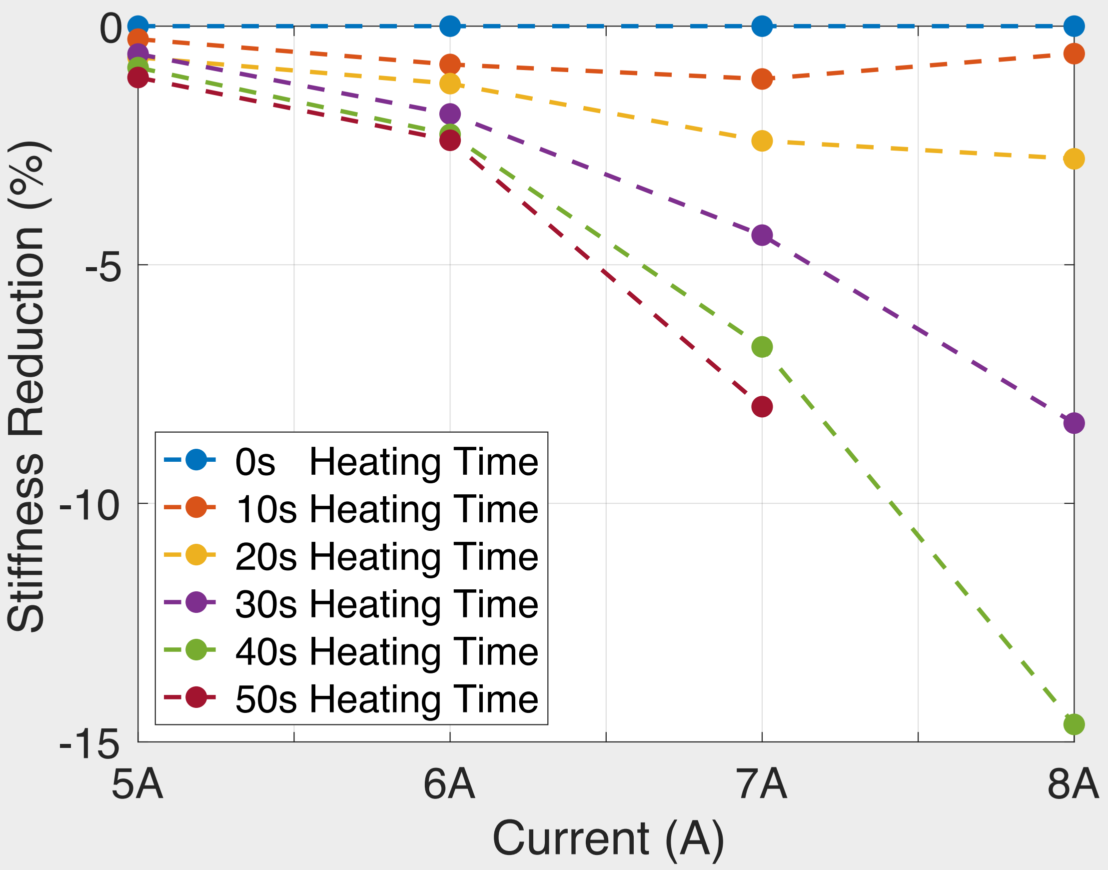
		Temperature (˚C)	Stiffness reduction
Control Sample	C-RT	Room Temp.	-
	C-120	120˚C	-17% relative to (C-RT)
	C-140	140˚C	-24% relative to (C-RT)
Int. PET samples	P-RT	Room Temp.	-18% relative to (C-RT)
	P-120	120˚C	-41% relative to (C-120)
	P-140	140˚C	-49% relative to (C-140)



- The PET led to a reduction in stiffness of 18% at room temperature
- The effect of thermoplastic softening in PET was demonstrated at elevated temperature, where the upper and lower CFRP plies could slide relative to each other leading to a reducing in stiffness
- Stiffness reduction of 41% and 49% was achieved in P-120 and P-140 respectively

Result and Discussion – Active Heating

Current (A)	Heating Time (s)	Stiffness (N/mm)	Stiffness reduction
0A	-	299.3	-
5A	10	298.5	-0.28%
5A	50	296.1	-1.08%
6A	10	296.9	-0.80%
6A	50	292.2	-2.39%
7A	10	296.0	-1.11%
7A	50	275.5	-7.95%
8A	10	297.6	-0.57%
8A	40	255.5	-14.63%



- No significant stiffness reduction was observed from 5A or 6A
- A stiffness reduction of 15% was achieved after pre-heating at 8A for a duration of 40s

Summary and Concluding Remarks

» Investigated the concept of variable stiffness through thermo-mechanical and electro-thermo-mechanical analysis

» Laminated composites with PET insert demonstrated the capability of variable stiffness

» Passive heating above the T_g of PET resulted in a maximum of 50% stiffness reduction

» The use of Joule heating resulted in a 15% stiffness reduction at a pre-heating time of 40 seconds at 8A

Thank you

Q & A