# INVESTIGATING THE INTERFACIAL HEALING PERFORMANCE OF A NEW VITRIMERIC SINGLE FIBER COMPOSITE

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## Introduction

- High and low-velocity impacts events can cause failure of structural composites during in-service applications
- These impacts may cause laminate and fiber/matrix debonding, which are difficult to detect and repair

Figure 1. Failed aircraft component.

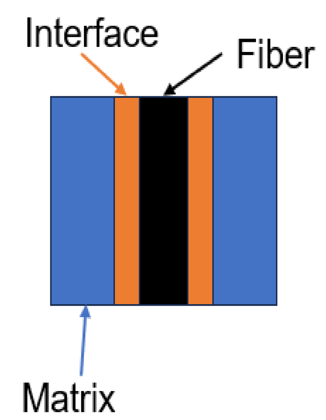



Figure 2. Schematic of a composite.

- Interface of a composite plays a huge important role as it ensures effective load transfer from matrix to fibers.
- Strategy to heal debonded interface at microlevel
  - Matrix with self-healing capability

## Research Gap

- Limited research work on the micromechanics of vitrimeric single fiber composites

## Aim and Objectives

- The main objective of this project is to evaluate the interfacial shear strength (IFSS) and demonstrate self-healing between the novel shape memory vitrimer and unsized intermediate modulus (Hexcel IM7) carbon fiber.

## Materials

- HexTow® unsized IM7.
- Shape memory vitrimer (SMV) composed of:
  - Branched polyethylenimine (bPEI)
  - Diglycidyl 1,2-cyclohexanedicarboxylate (DCN)
  - The monomer feed ratios play a huge role on the glass transition temperature of the SMV

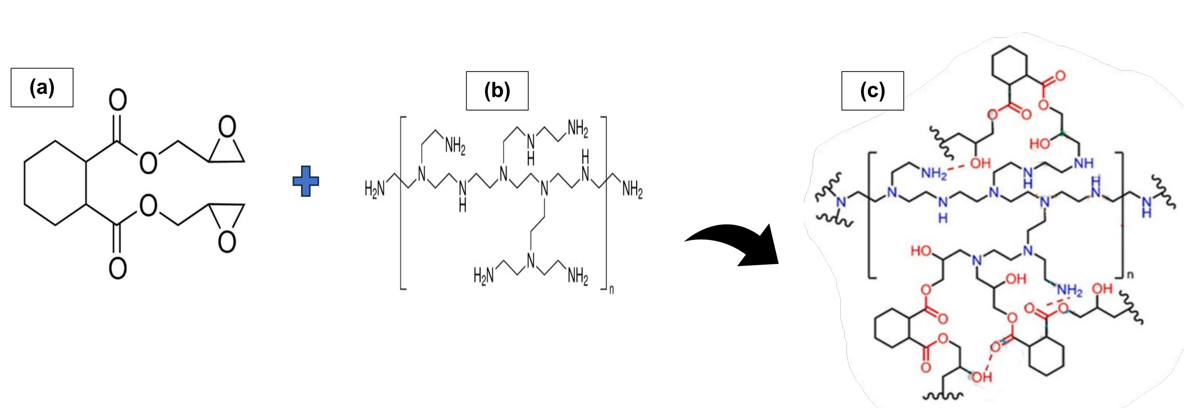



Figure 3. Chemical structure of monomers: (a) bPEI and (b) DCN; (c) Synthesis route of the SMV [1]

## Differential Scanning Calorimetry (DSC)

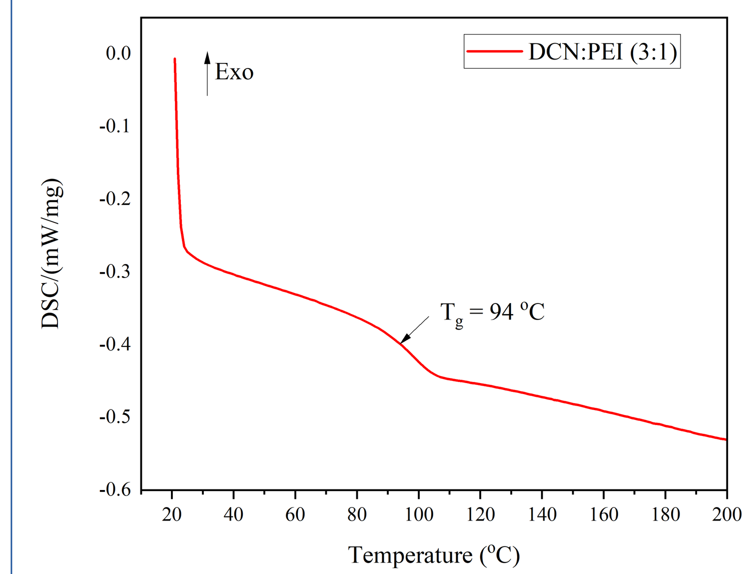



Figure 4. DSC plot of the SMV

| Vitrimer system (DCN:PEI) | Tg (°C) |
|---|---|
| 1:1 | 41.6 [1] |
| 2:1 | 80 |
| 3:1 | 94 |

Vitrimer with 3:1 formulation was chosen to obtain a higher Tg suitable for structural applications.

## Single Fiber Pullout Testing

The IFSS was conducted using single fiber pullout test where a single fiber is embedded in a molten matrix at a pre-determined depth.

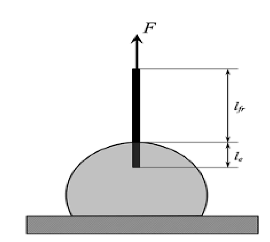


Figure 5. Schematic of a single fiber pullout test [2].

The IFSS was determined using Equation 1.

$$\tau_{IFSS} = \frac{F_{max}}{\pi \times d \times l_e} \;\; ............ \;\; (1)$$

where $F_{max}$ is the maximum force (cN), d is the diameter of the fiber (μm), and $l_e$ is the embedded length (μm).

A pullout test is declared successful if the matrix and the fiber interface fail before tensile fiber failure.

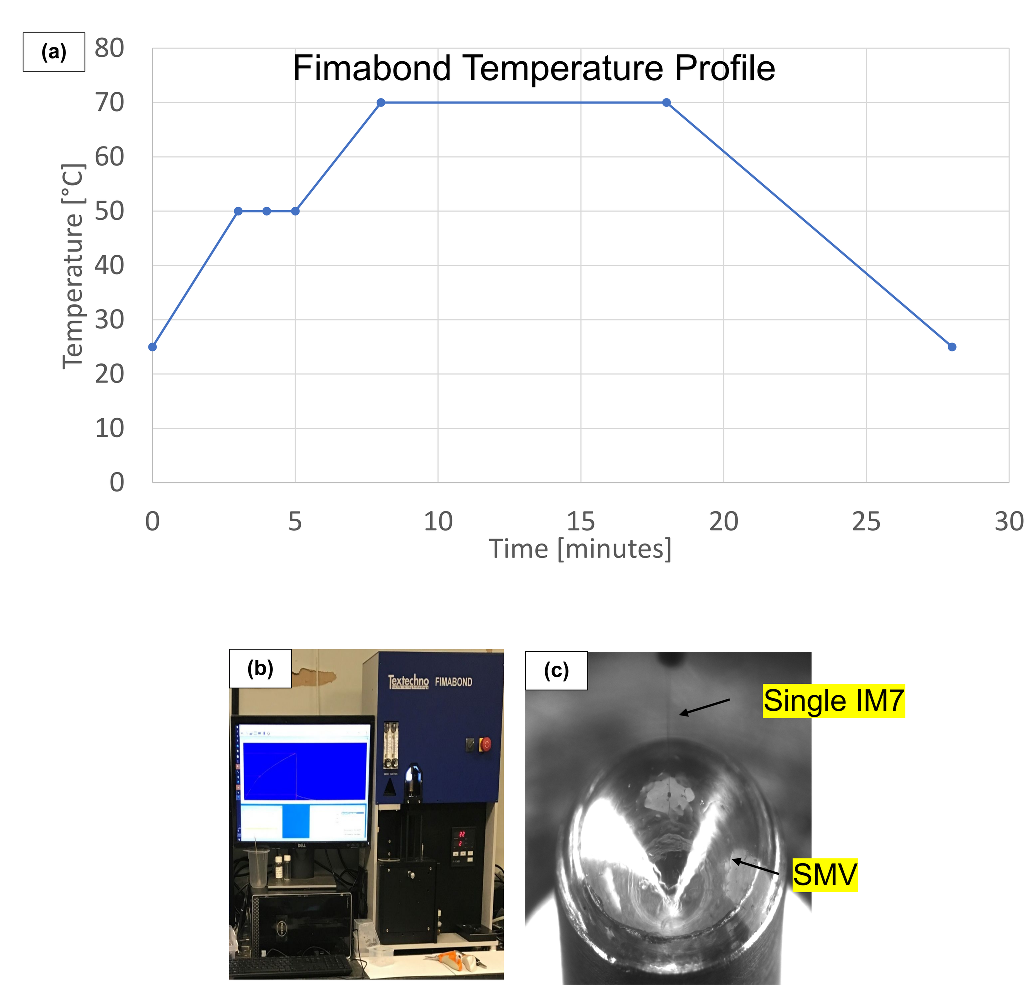



Figure 6. (a) Fimabond temperature profile, (b) Fimabond for making single fiber composites, and (c) as-fabricated single fiber composite.

- Single fiber pullout tests were conducted using a custom Favimat+ tester with 200 cN load cell.
- The embedded length and fiber diameter determined from the SEM micrographs.

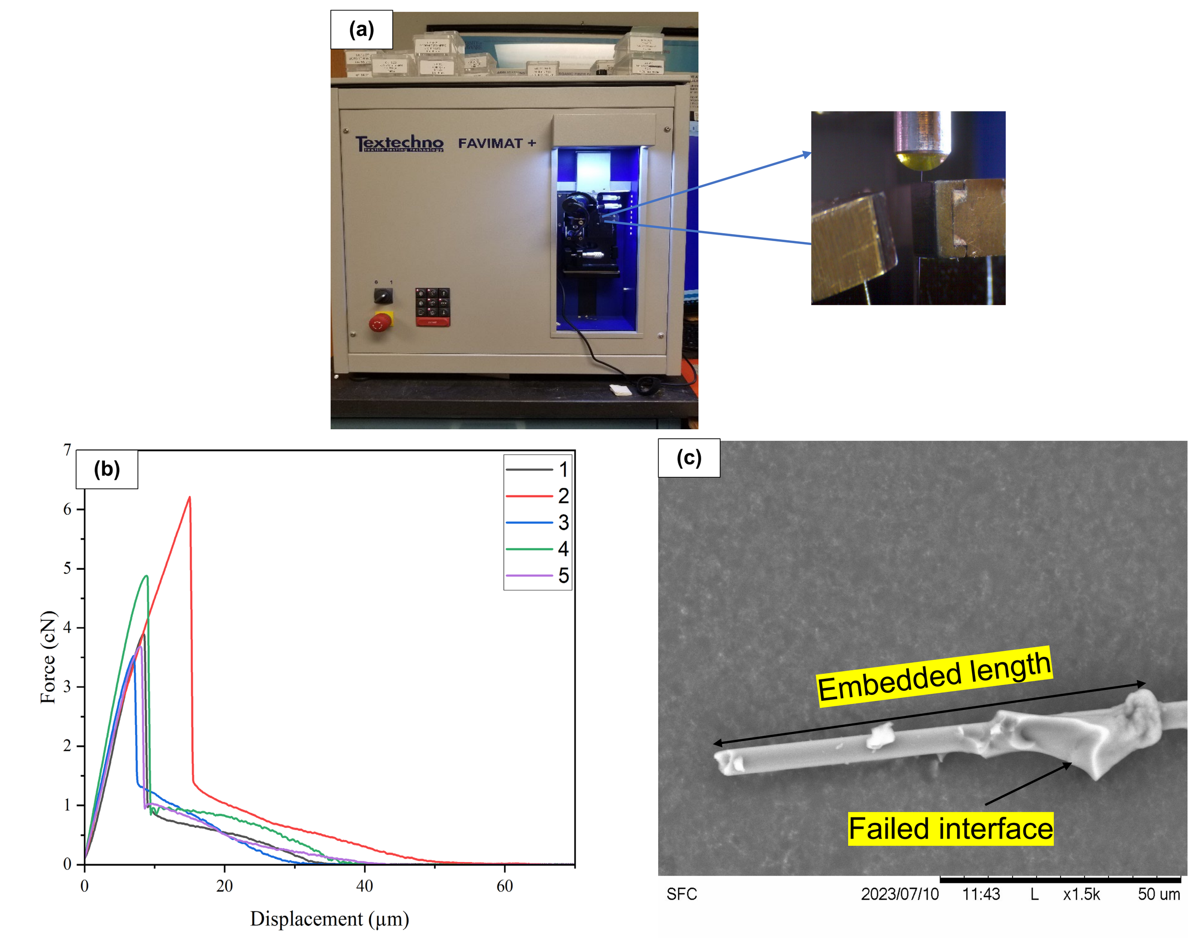



Figure 7. (a) Custom equipment used for pull-out testing, (b) Force-displacement curves of the single fiber composites, and (c) SEM micrograph of a failed interface

| Fiber diameter (μm) | Le (μm) | IFSS (MPa) |
|---|---|---|
| 5.0 ± 0.1 | 47.1 ± 6.4 | 60.2 ± 10.5 |

## Healing conditions for interfacial healing experiments

The conditions for the interfacial healing experiment were determined using temperature-dependent stress-relaxation and lap shear experiment.

### Stress-Relaxation Experiments

- The temperature required for bond exchange reactions (BERs) in the SMV was found to be 160 °C, Based on the obtained $T_v$, temperature-dependent relaxation tests were conducted at different temperatures (160, 170, 180, 190, and 200 °C) to investigate the relaxation behavior of the vitrimer at these temperatures.
- Relaxation time increases with increasing temperature.

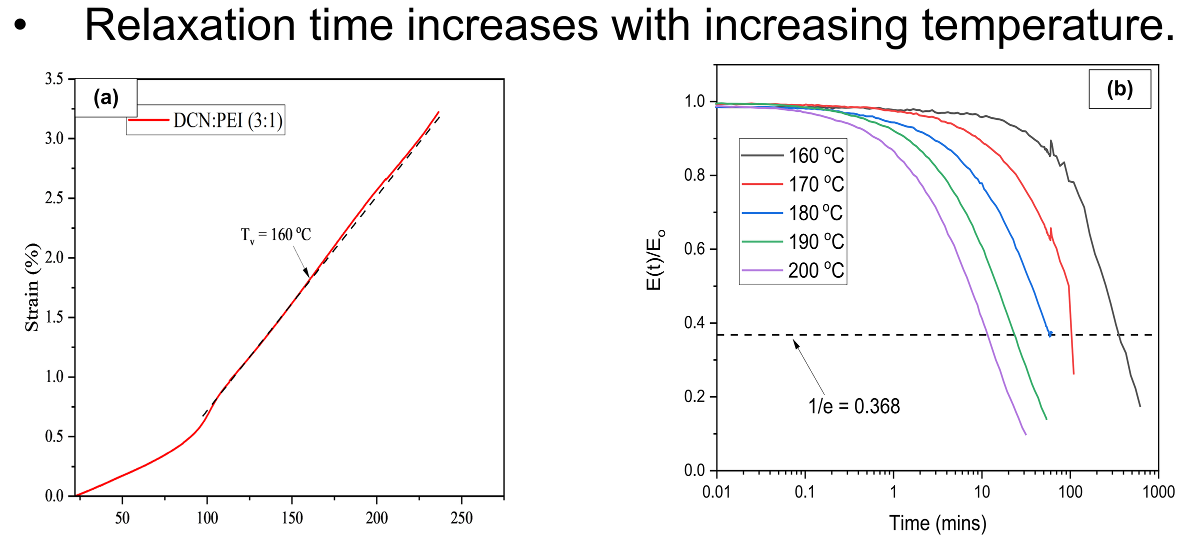
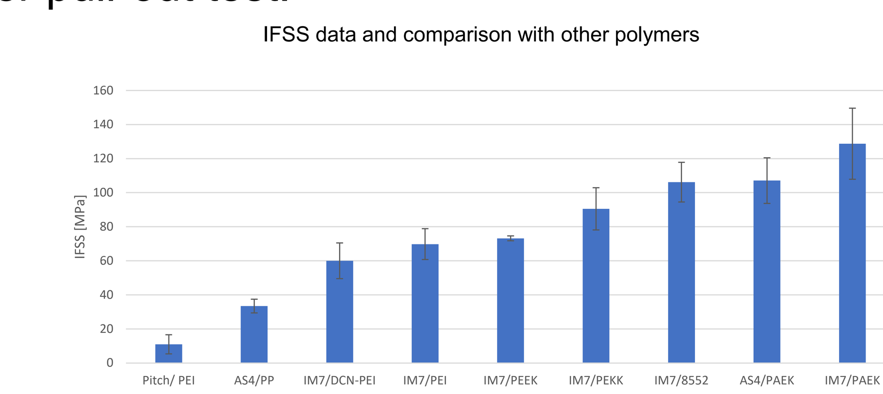


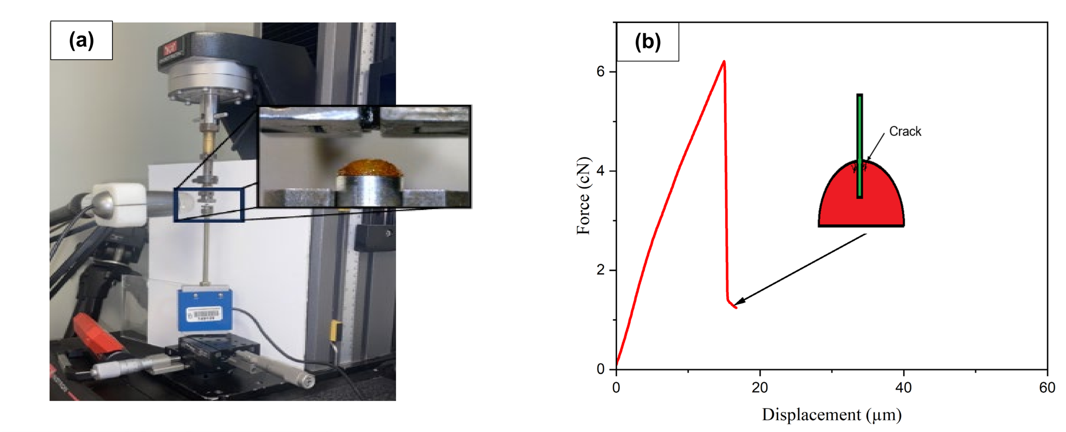

Figure 8. (a) Results from dilatometry and (b) Stress-relaxation plots of the SMV.

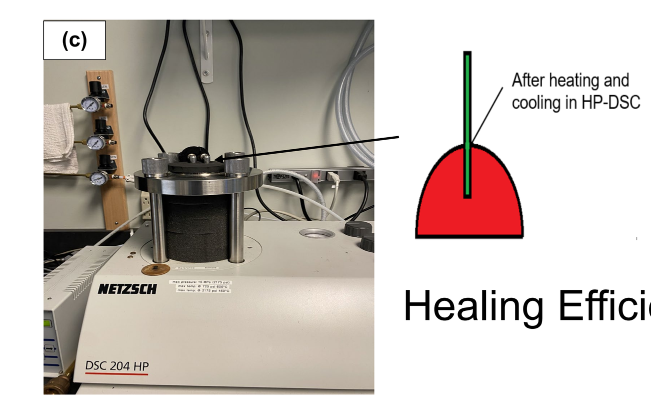
## Conclusion and Path Forward

- The IFSS of a new single fiber thermoset based vitrimeric composite with evaluated using a single fiber pull-out test.




- Self-healing of the debonded interface will be investigated in the next steps as shown below.




$$\text{Healing Efficiency} = \frac{IFSS_{healed}}{IFSS_{virgin}} \; x \; 100\% \; ... \; (2)$$

Figure 9. Approach adopted for self-healing of the debonded interface: (a) Mini-Intron 5944 for conducting partial pullout tests, (b) Debonding of the virgin interface and (c) Healing of the debonded interface using High-pressure-DSC.

## References

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2. S. Zhandarov, E. Mäder, C. Scheffler, G. Kalinka, C. Poitzsch, and S. Fliescher, "Investigation of interfacial strength parameters in polymer matrix composites: Compatibility and reproducibility," *Adv. Ind. Eng. Polym. Res.*, vol. 1, no. 1, pp. 82–92, 2018, doi: 10.1016/j.aiepr.2018.06.002.

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