Delamination Toughening of Composites Using Different Types Of Tufting Materials

Presented by

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What's next...

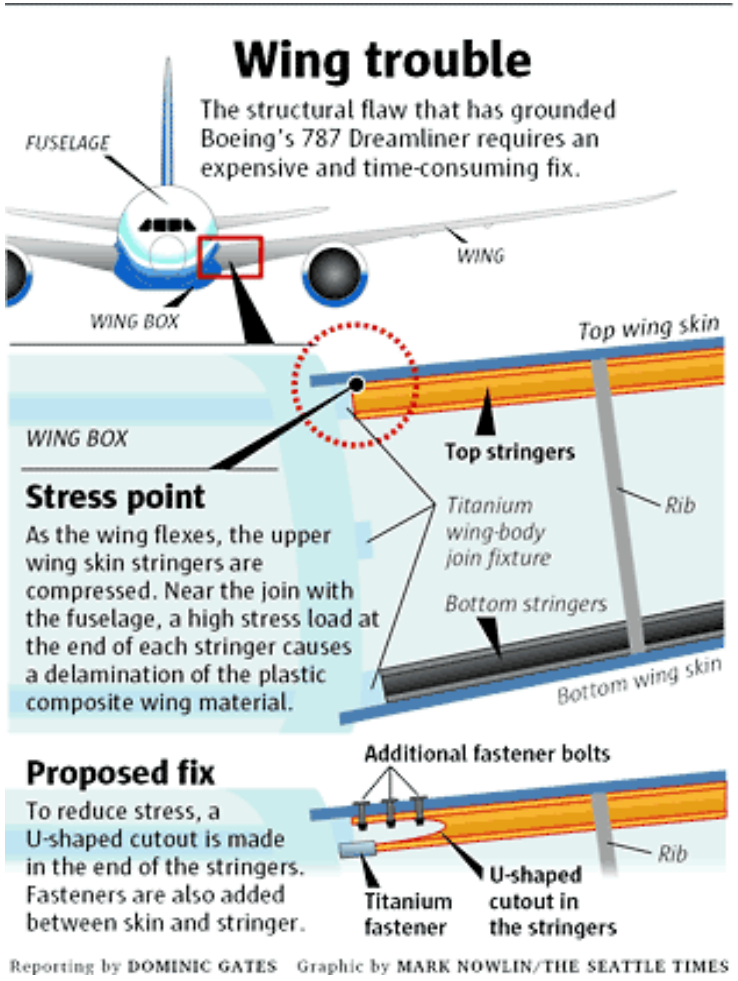
Introduction – 3D Reinforced Composites

- Delamination from
  - Impact damage
  - Fatigue loading
  - Overloading
- Through the thickness thermal and electrical conductivity

Non-destructive testing (NDT) technique

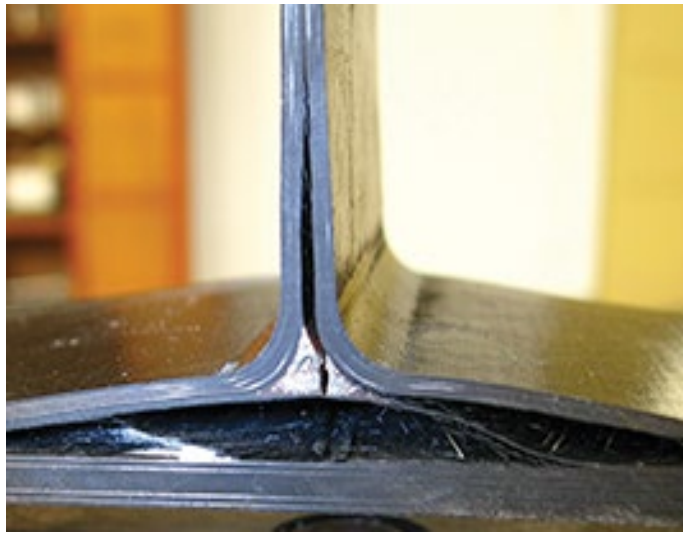
https://www.aerospacetestinginternational.com/features/introduction-to-non-destructive-testing.html

Boeing 787 Dreamliner Stringer problem



https://kirill-guevara.livejournal.com/117050.html

Delamination damage on T-joint composites

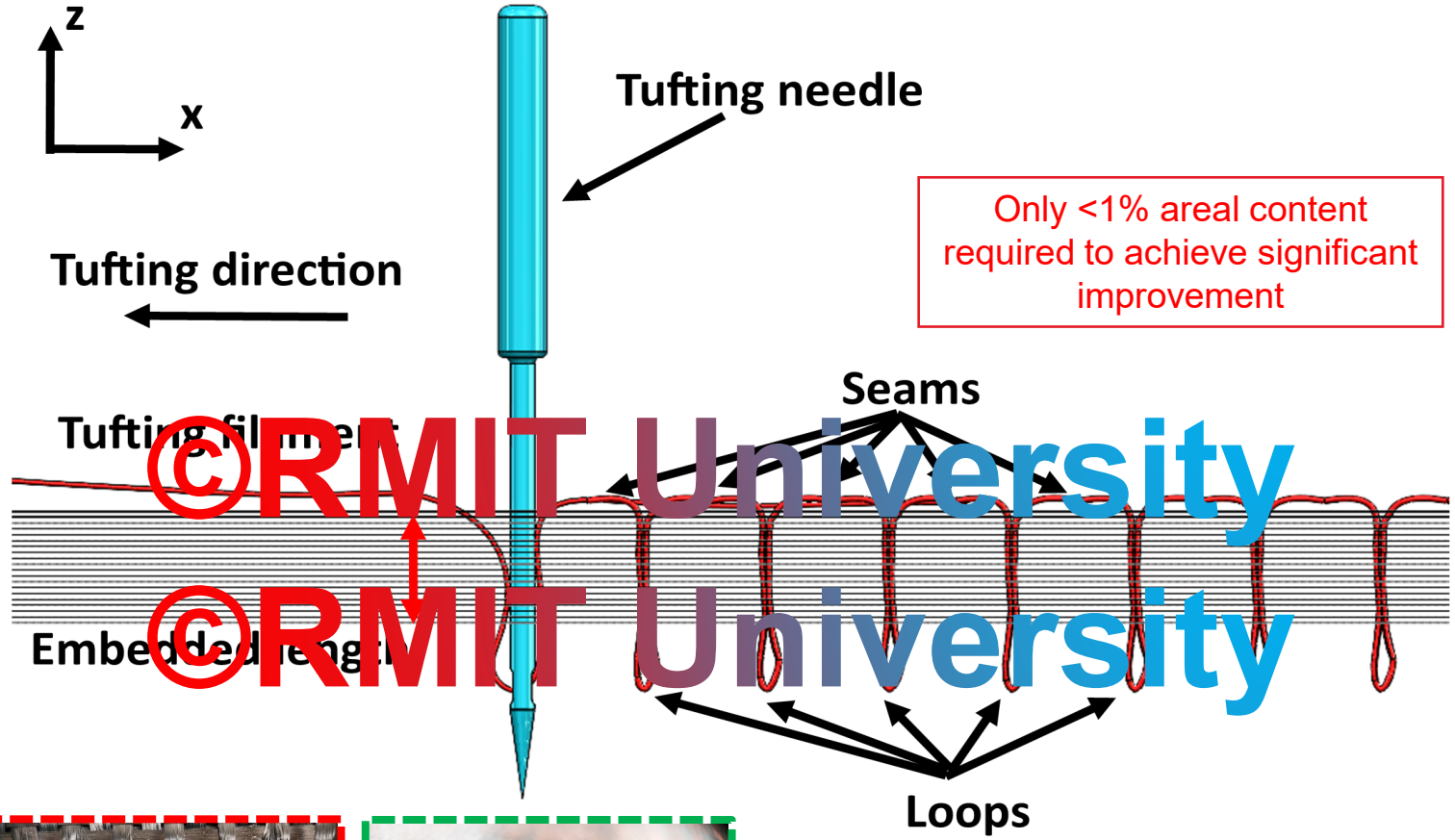


https://www.engineerlive.com/content/composites-aircraft-improve-performance-there-are-challenges

Lightning strike damage

https://www.boeing.com/commercial/aeromagazine/articles/2012_q4/4/

Methodology – Tufted Composites



Only <1% areal content required to achieve significant improvement

Tufted composites

- Access required on one side only
- Can be used with fibrous based material and metal filament
- Can be automated
- Flexible process parameters (Tufting direction, embedded length, embedded angle, pattern)

Methodology – Tufted Composites

Shape Memory Alloy (SMA) wires

- Made of Nickel(Ni) and Titanium(Ti)
- Thermal Activated Shape Memory Alloy (SMA) wires
- Unique properties for many applications
  - Strain gauge
  - Damage detection
  - Shape morphing
  - Self-healing
  - Damping

Results:

- **Structural and Mechanical properties improvement**
  - **Delamination resistance**
  - **Fatigue resistance**
- **Multifunctional Properties engendered**

Benchmarking against Conventional Tufting materials

- **Carbon and**
- **Kevlar**

Metal filament:

- **Copper filament**

Results and Discussions

Mode I Interlaminar Fracture Toughness of Aramid, Carbon, Copper and SMA Tufts

Mode I Interlaminar Fracture Toughness

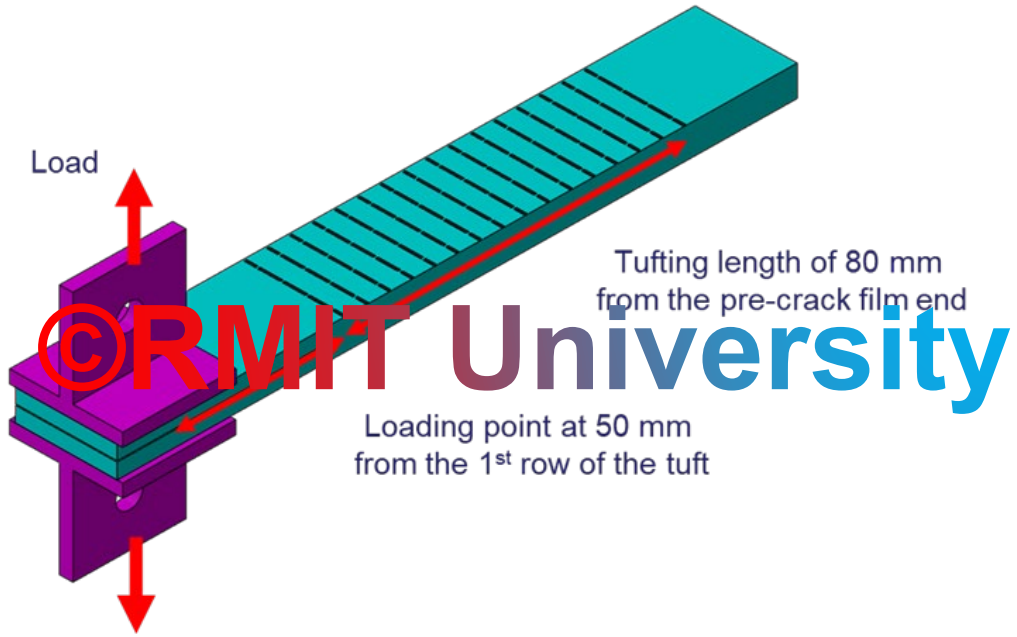
Tufted Composites

- 200 gsm Plain Woven Composites
- Tufting materials: Aramid, Carbon, Copper and SMA wire
- %Areal content of 0.30%
- Vacuum assisted resin infusion

Methodology

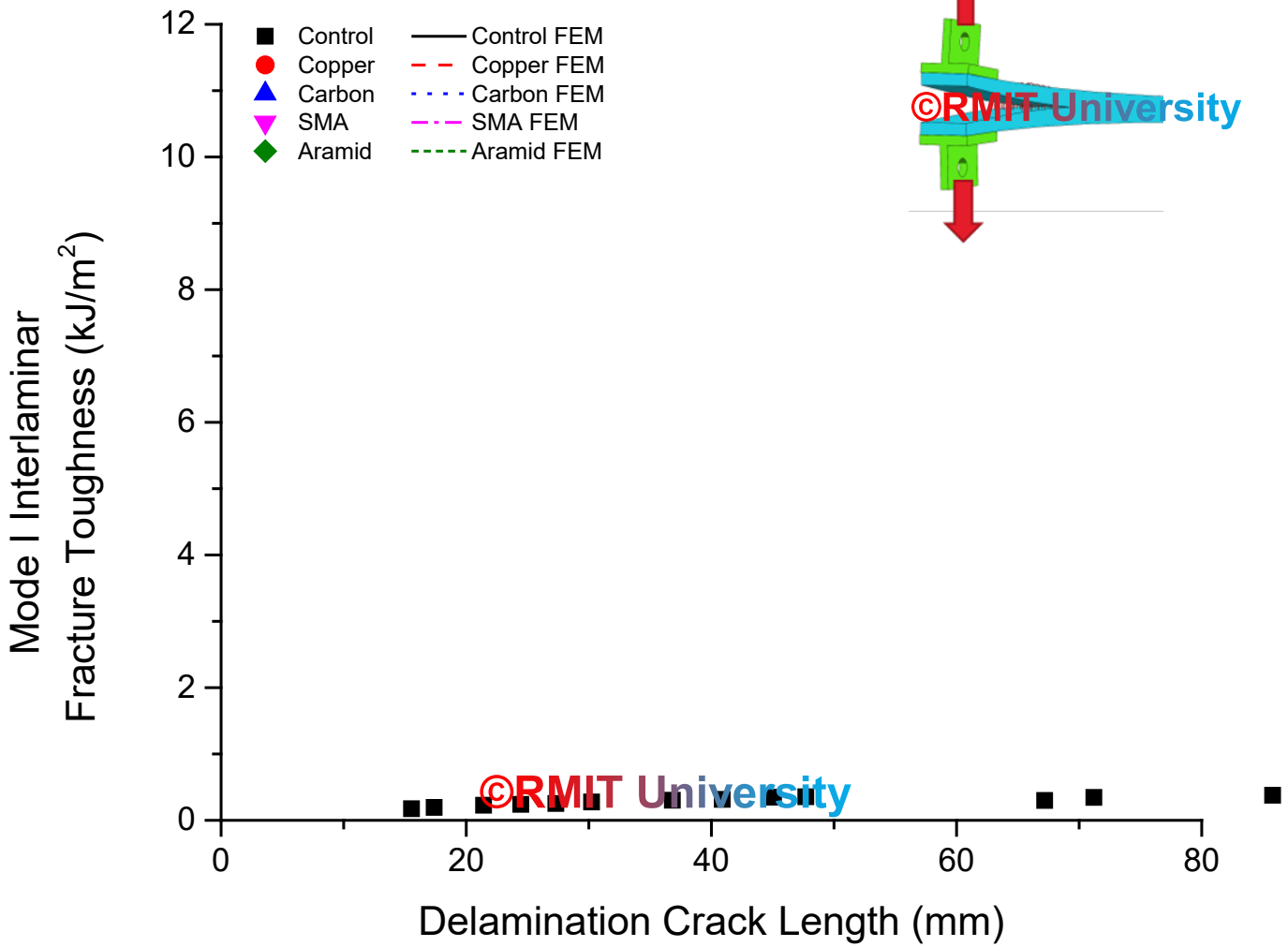
- **Mode I** Interlaminar Fracture toughness

(Double Cantilever Beam (DCB)) test – ASTM D5528



Double Cantilever Beam (DCB) test – ASTM D5528 standard

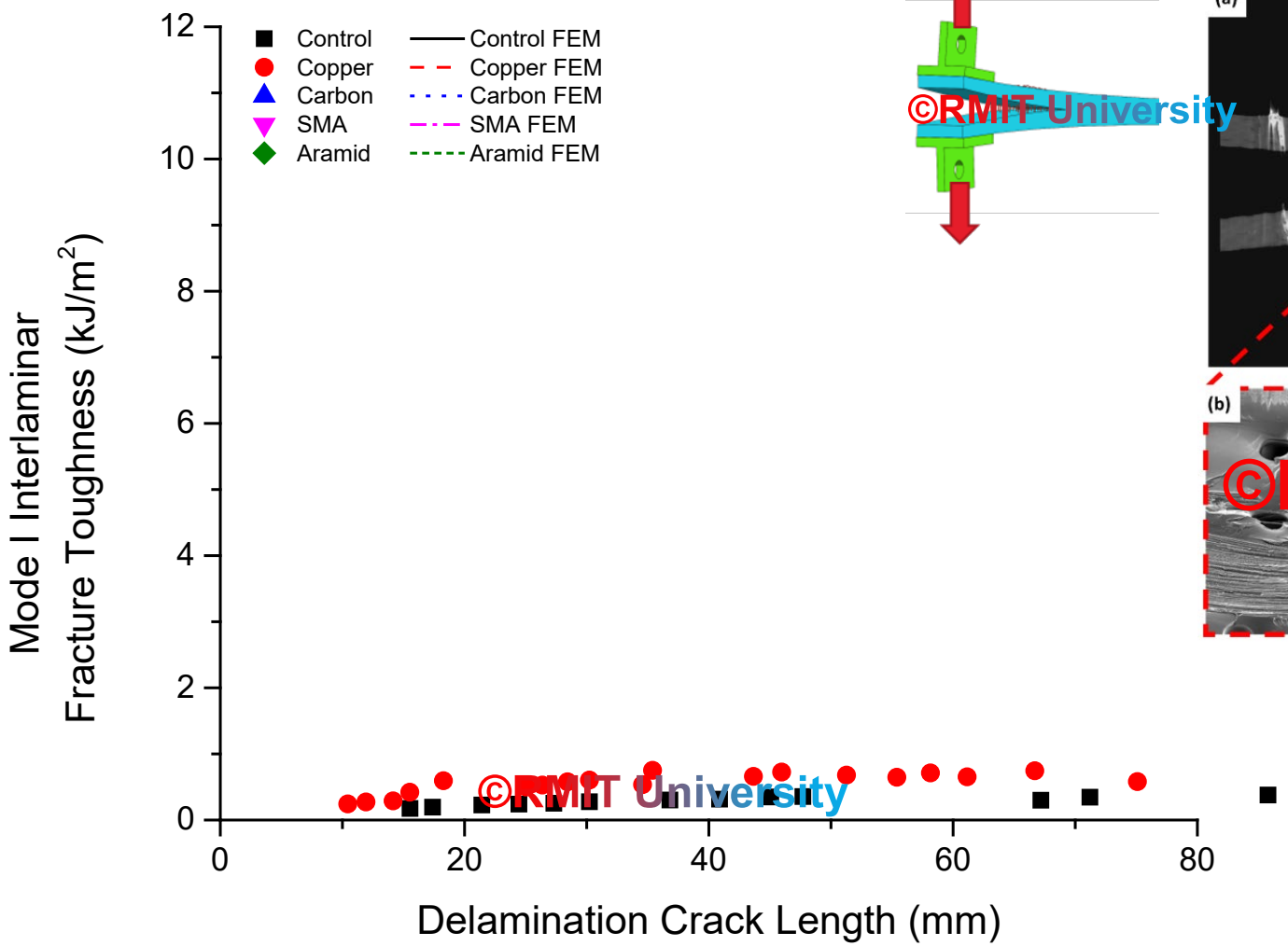
Mode I Interlaminar Fracture Toughness

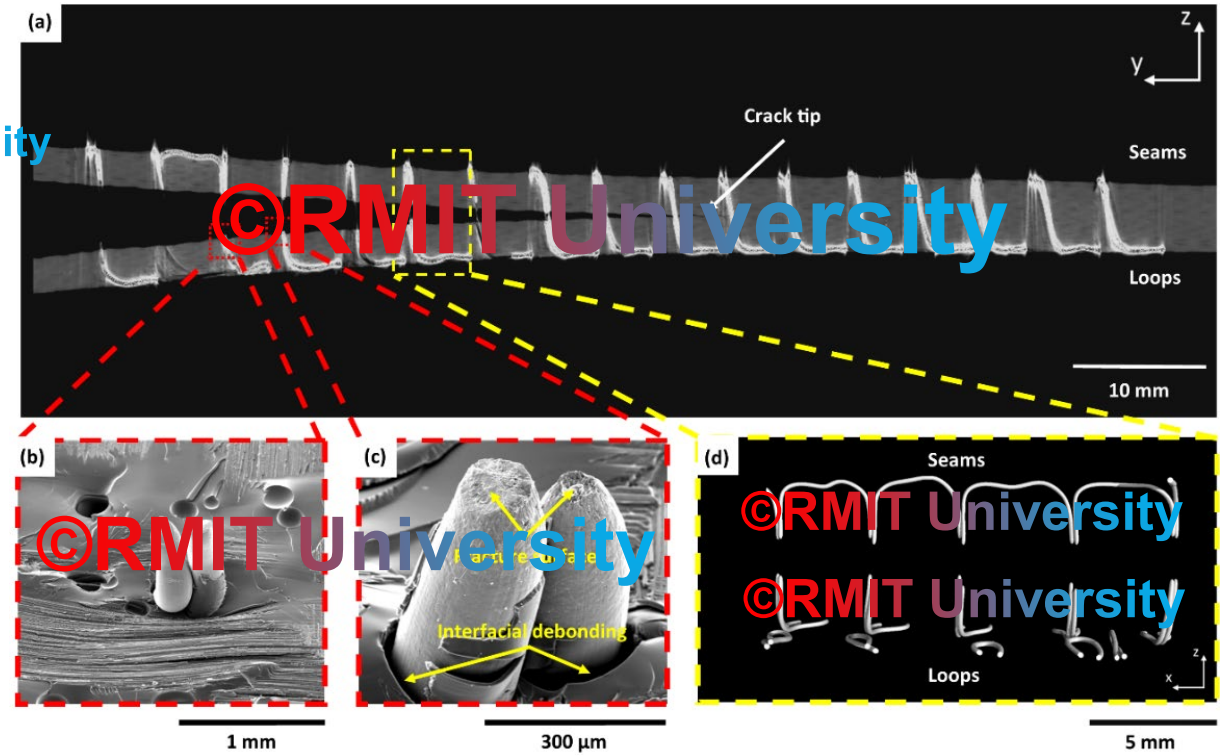


Control sample

- **No tufts inside**
- **Steady state value of 0.42 kJ/m²**

Mode I Interlaminar Fracture Toughness

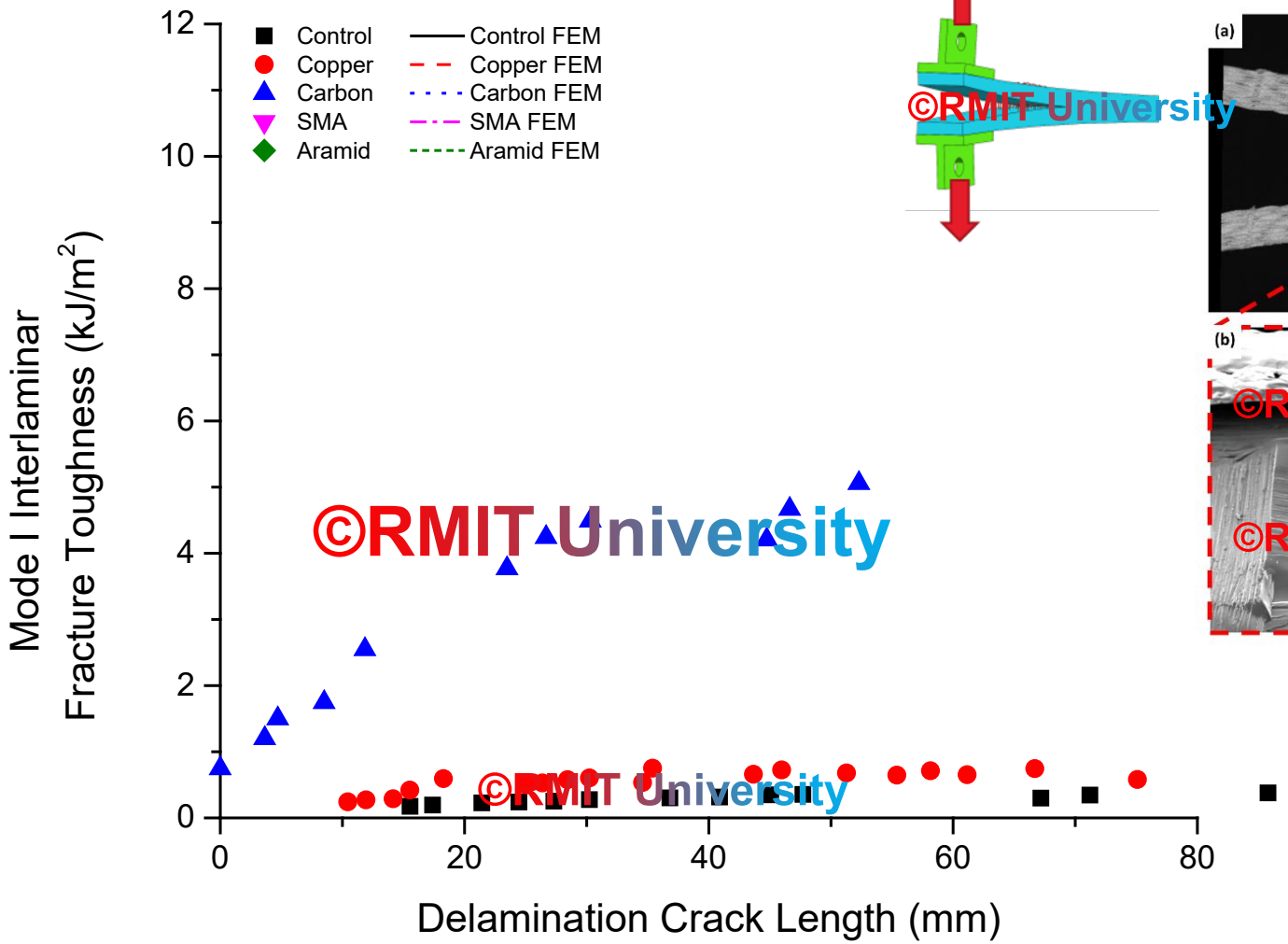


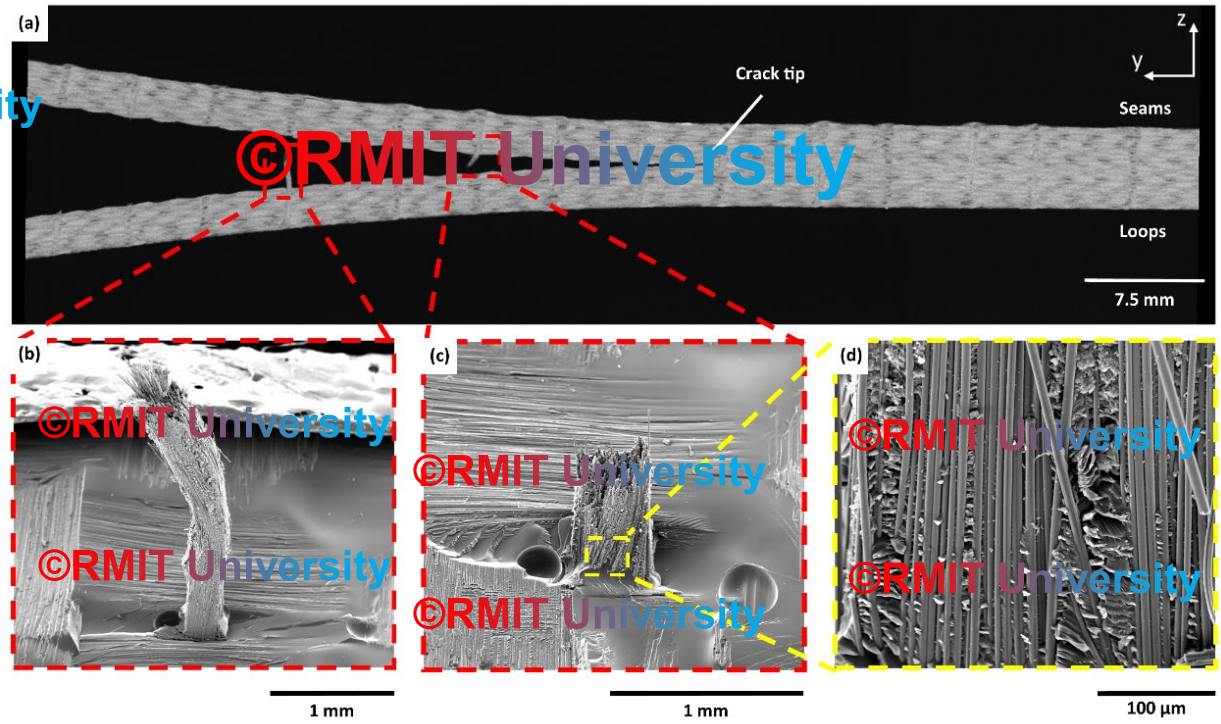


Copper tufted sample

- **Steady state value of 0.63 kJ/m2**
- **+49% Improvement**

Mode I Interlaminar Fracture Toughness

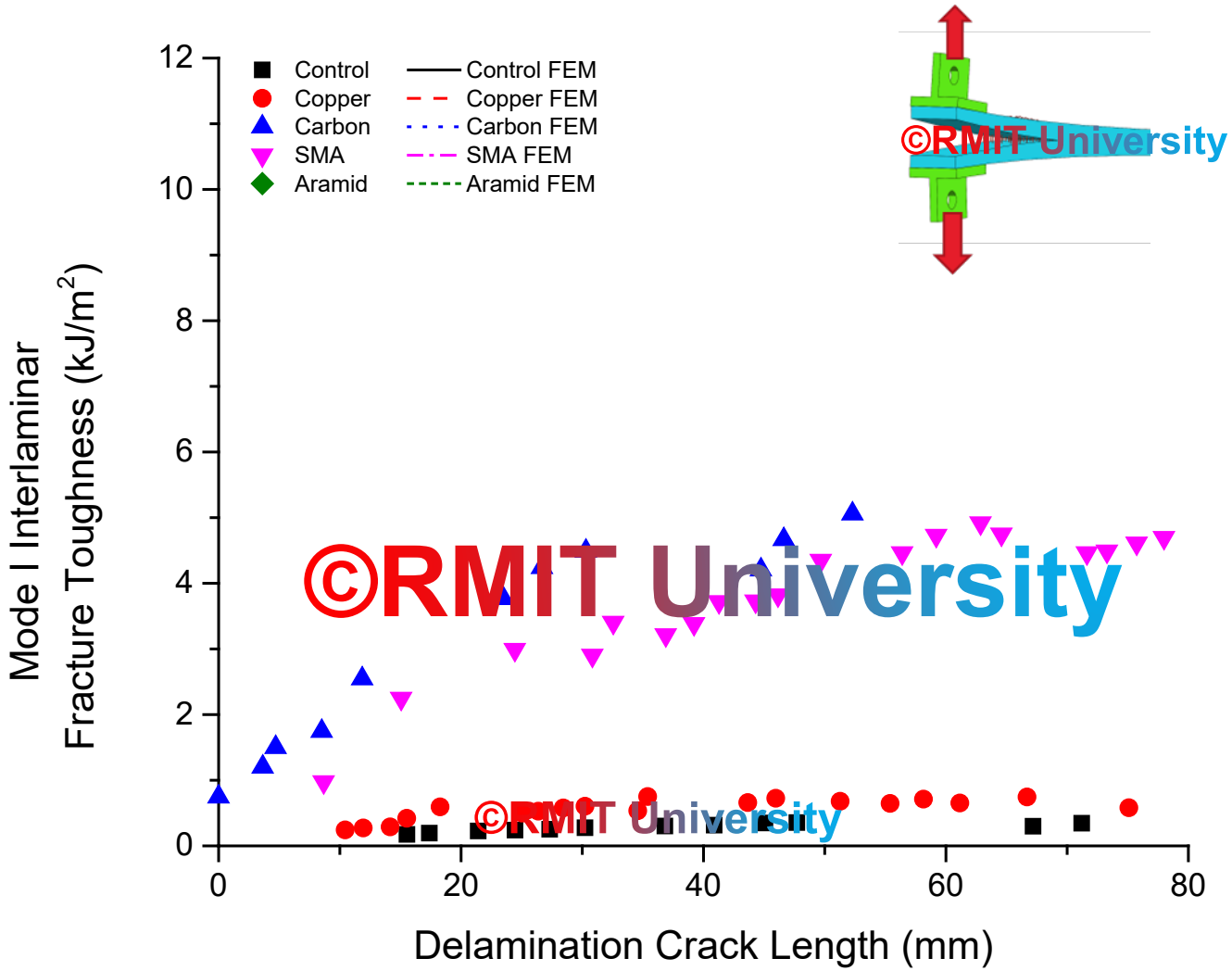


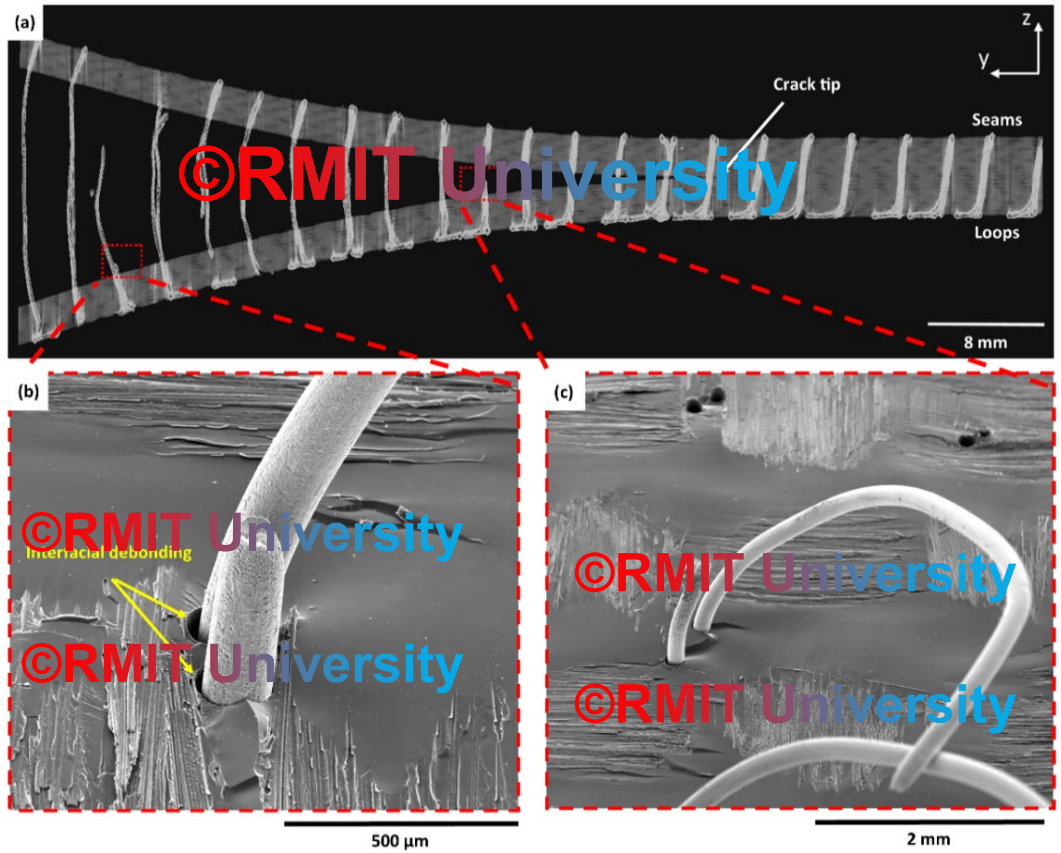


Carbon tufted sample

- **Steady state value of 2.86 kJ/m²**
- **~ 9 folds improvement**

Mode I Interlaminar Fracture Toughness

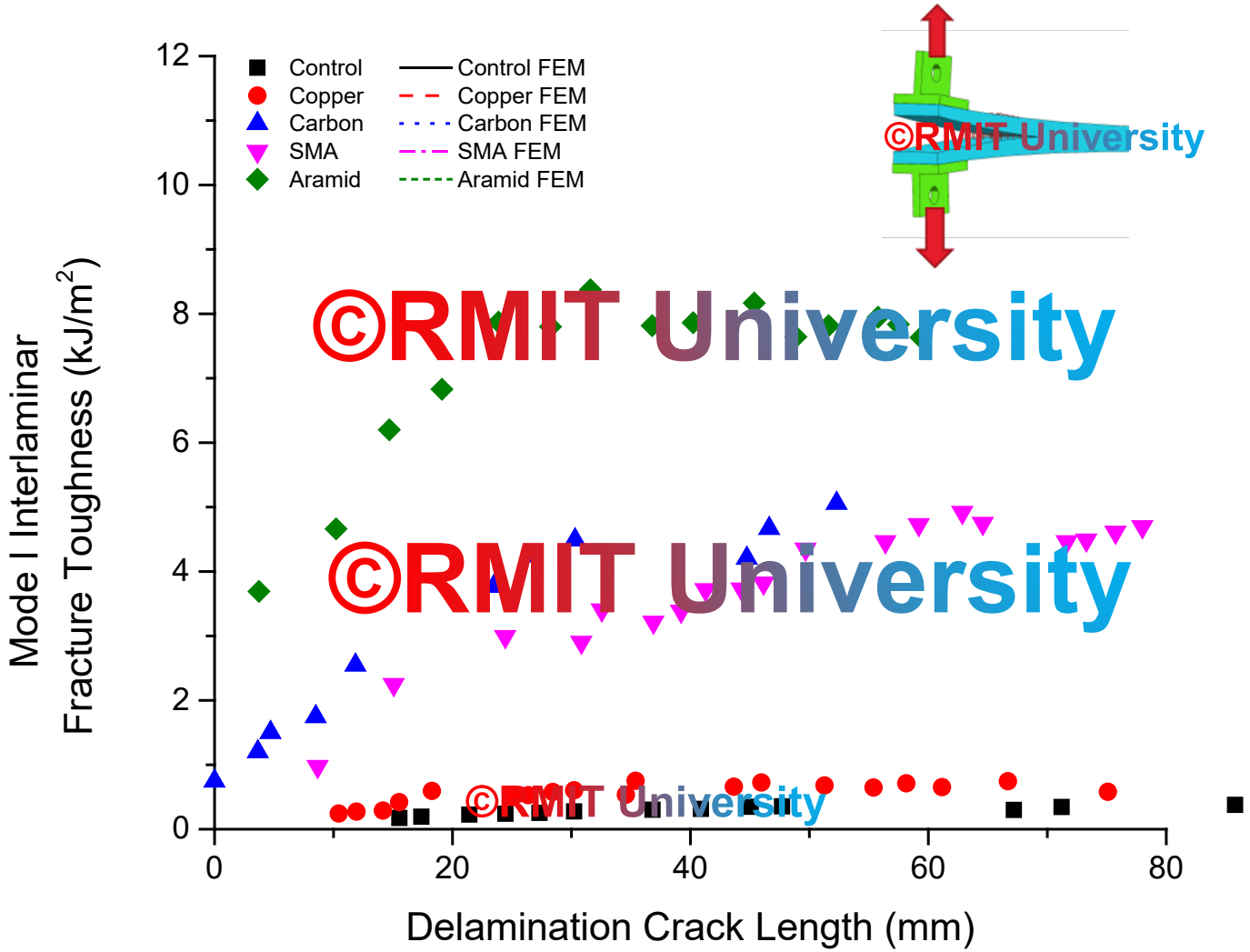


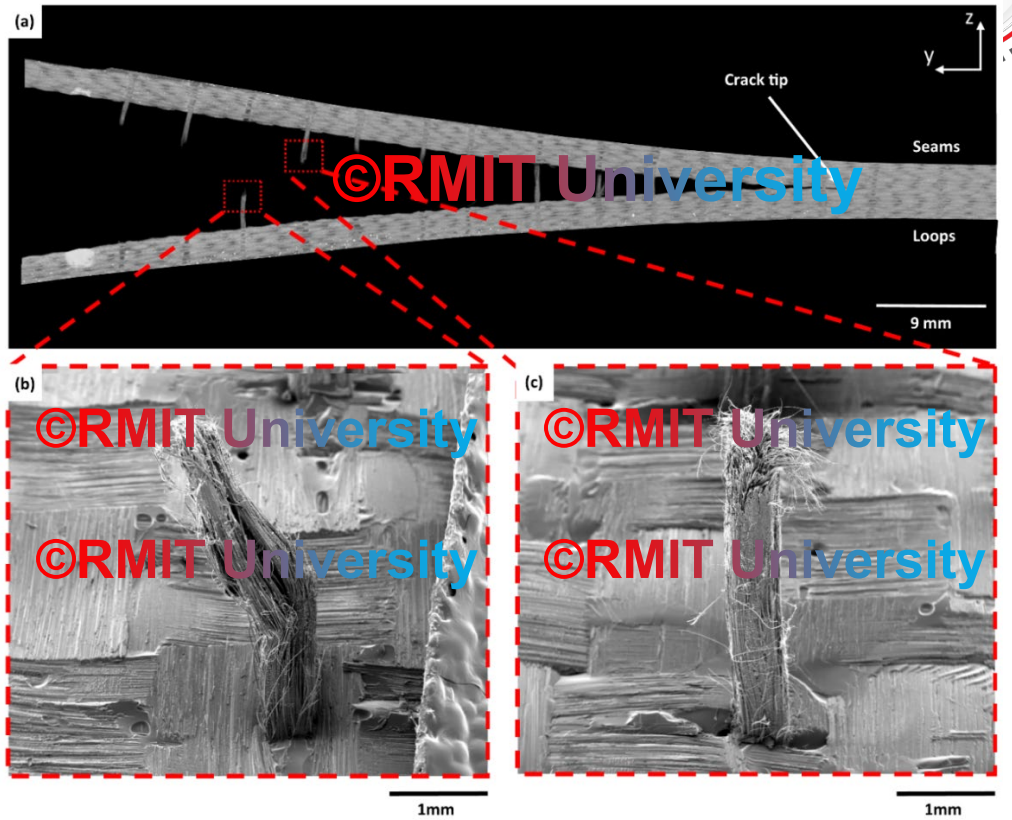


SMA tufted sample

- **Steady state value of 4.34 kJ/m²**
- **~ 9 folds improvement**
- **Large bridging scale observed**

Mode I Interlaminar Fracture Toughness





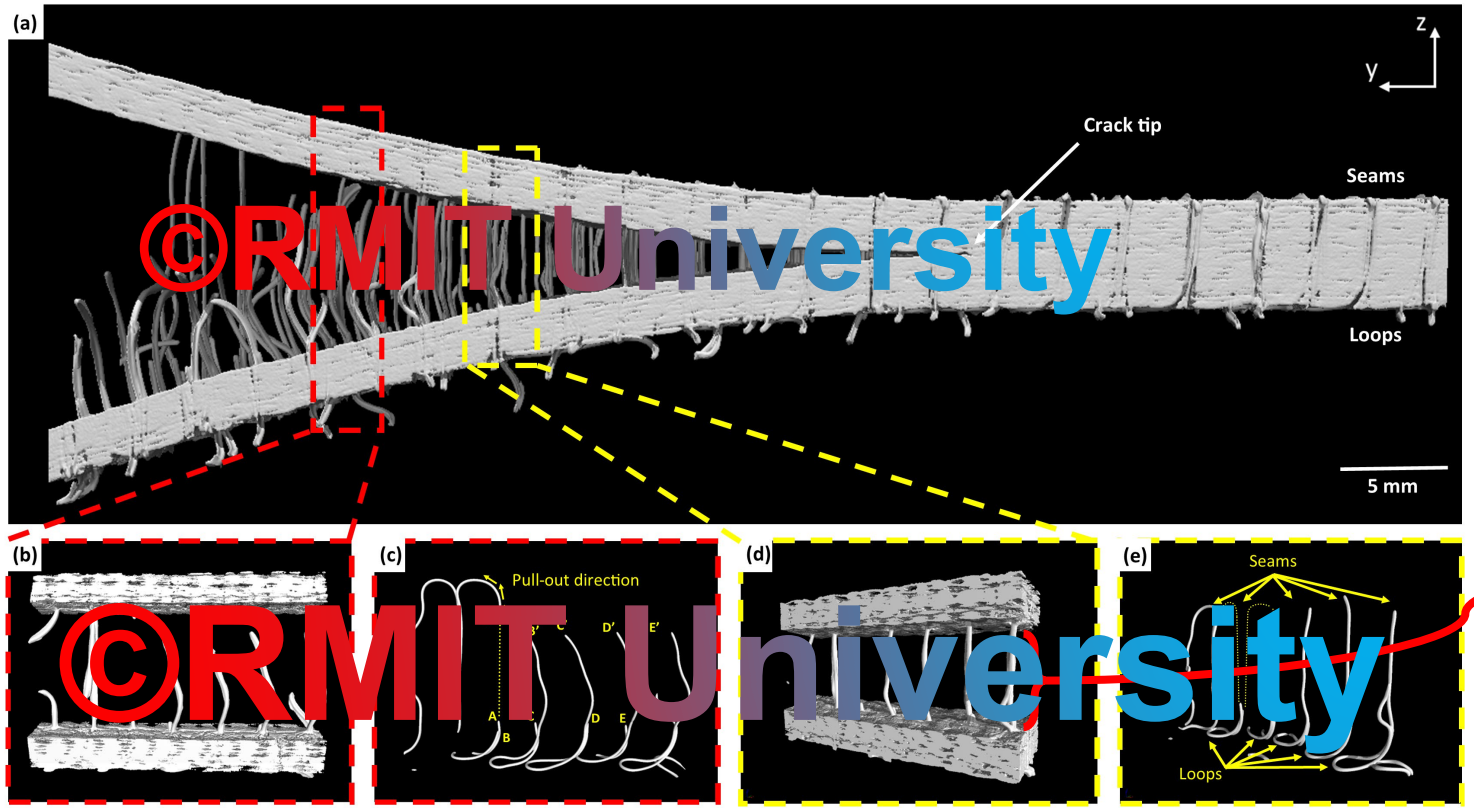
Aramid tufted sample

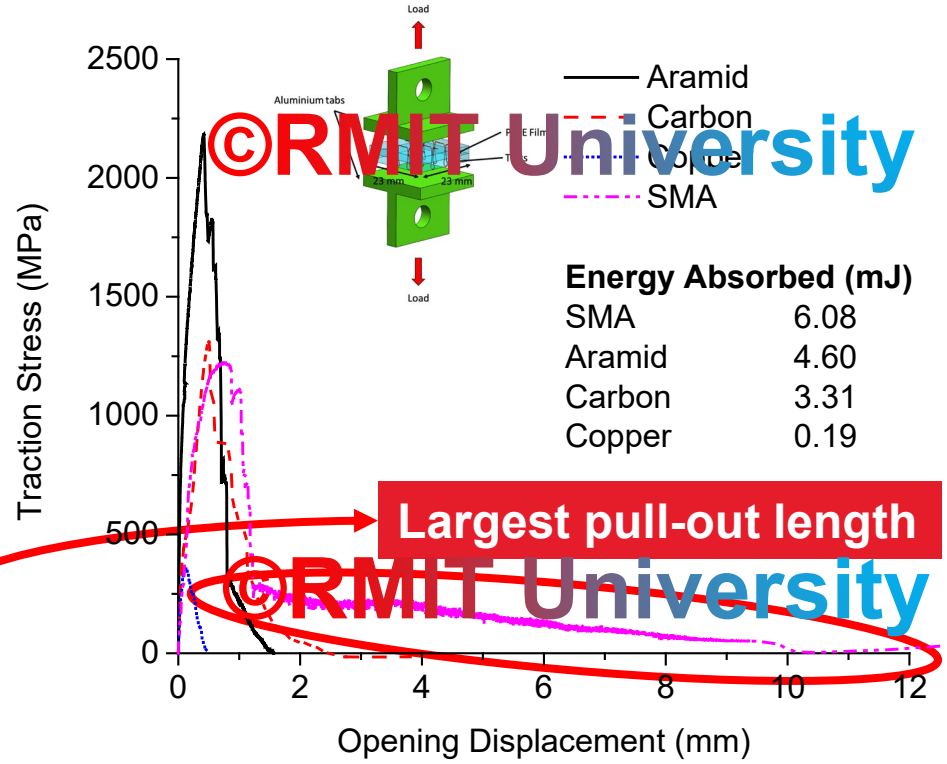
- **Steady state value of 7.96 kJ/m²**
- **~ 18 folds improvement**
- **Highest improvement observed**

Mode I Interlaminar Fracture Toughness

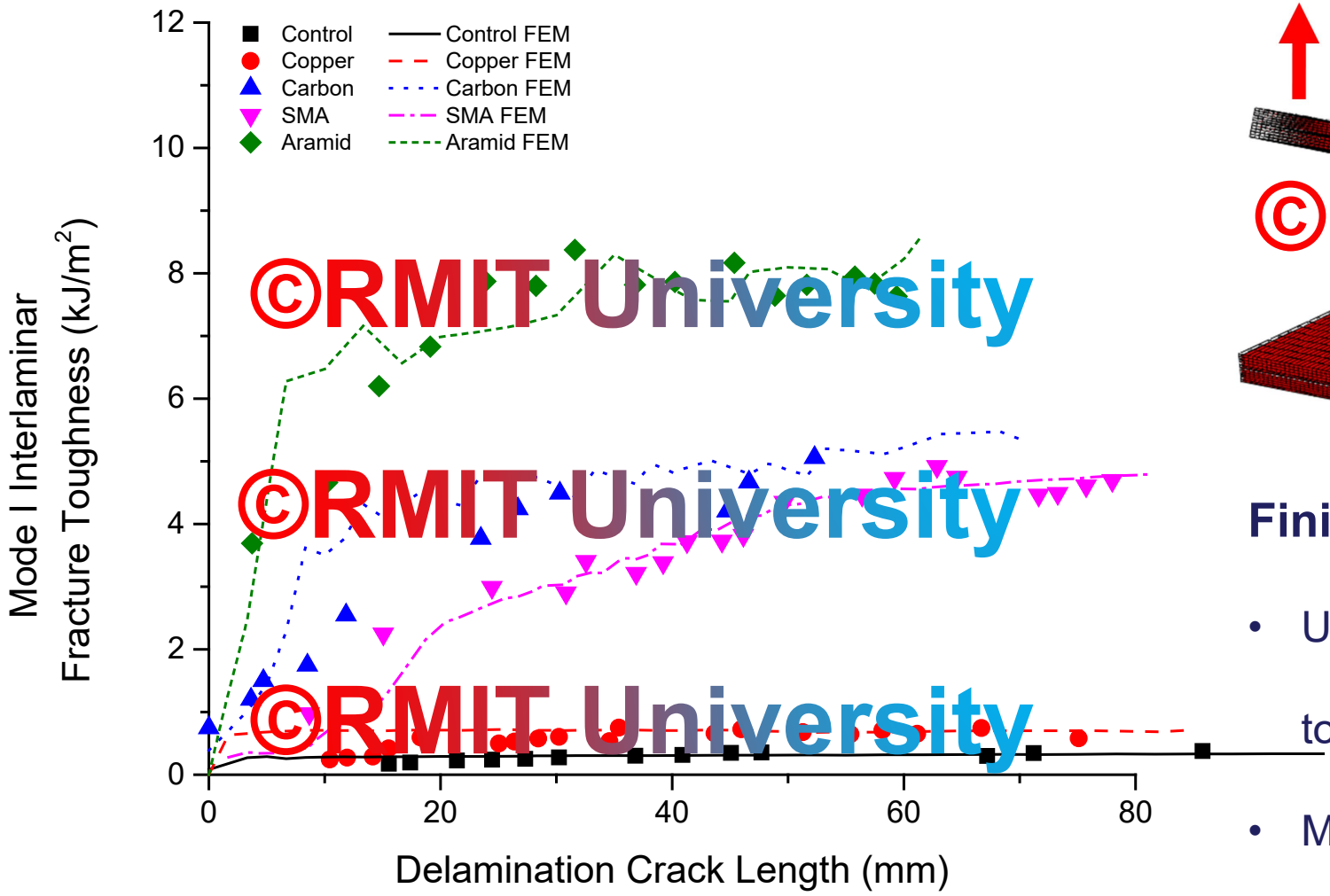
Toughening Mechanism due to "Large scale-bridging zone"

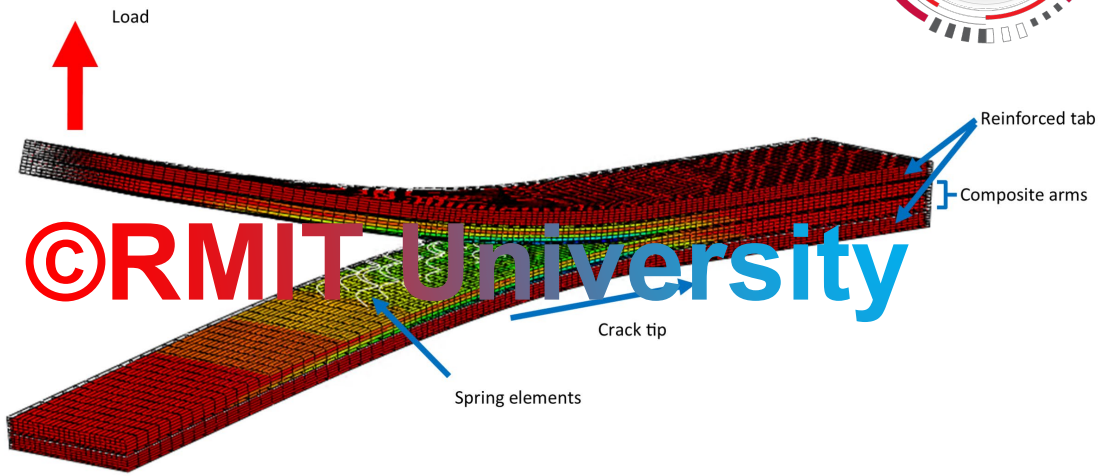
- Increased required force to propagate the crack
- Depending on pull-out mechanism of the tuft type – SMA showing largest amount of pull out





Mode I Interlaminar Fracture Toughness





Finite Element Modelling

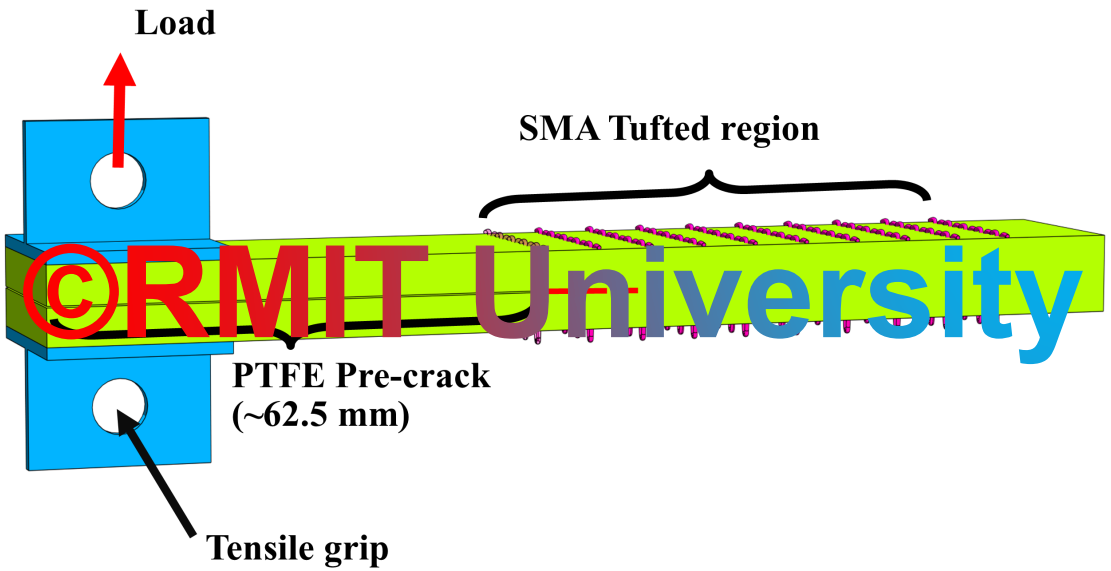
- Using spring element (built-in Abaqus feature) to represent tufts
- Modified spring law using traction load law as a guide

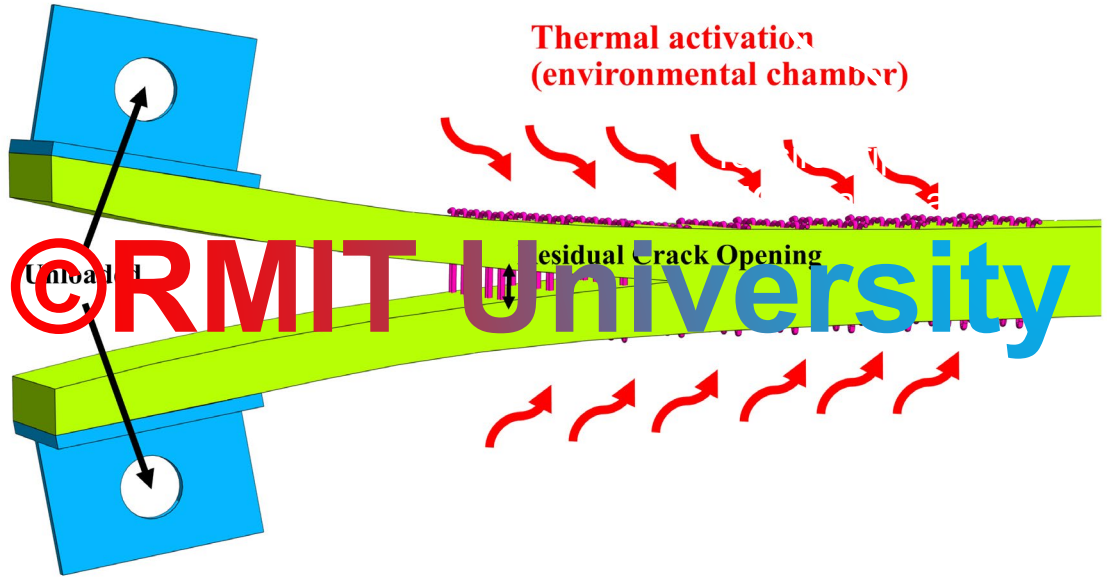
Results and Discussions

Delamination Crack Closure of SMA tufts using large(0.25 mm) and small (0.15 mm) SMA wires at different propagation length

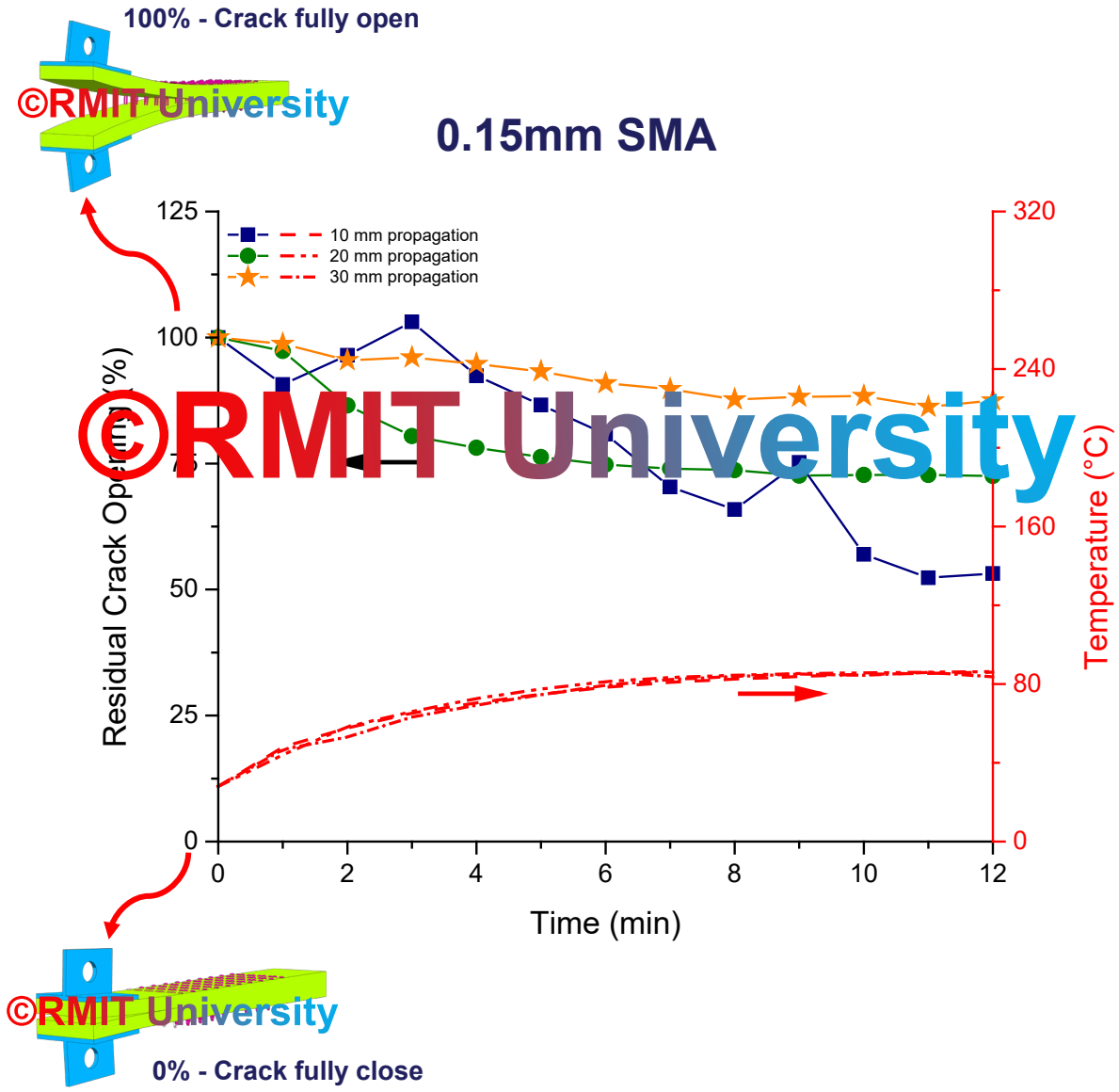
Delamination Crack Closure of SMA Tufts

- Using environmental chamber on Instron 50.1 kN machine
- Sample was tufted with 0.15 and 0.25 mm SMA as tufts at 0.3% areal content
- SMA wire transition temperature: 80 ºC
- DIC Was used
- Mode I delamination crack closure
  - Efficacy at different propagation lengths
  - Efficacy test at fixed propagation length (4 cycles test)

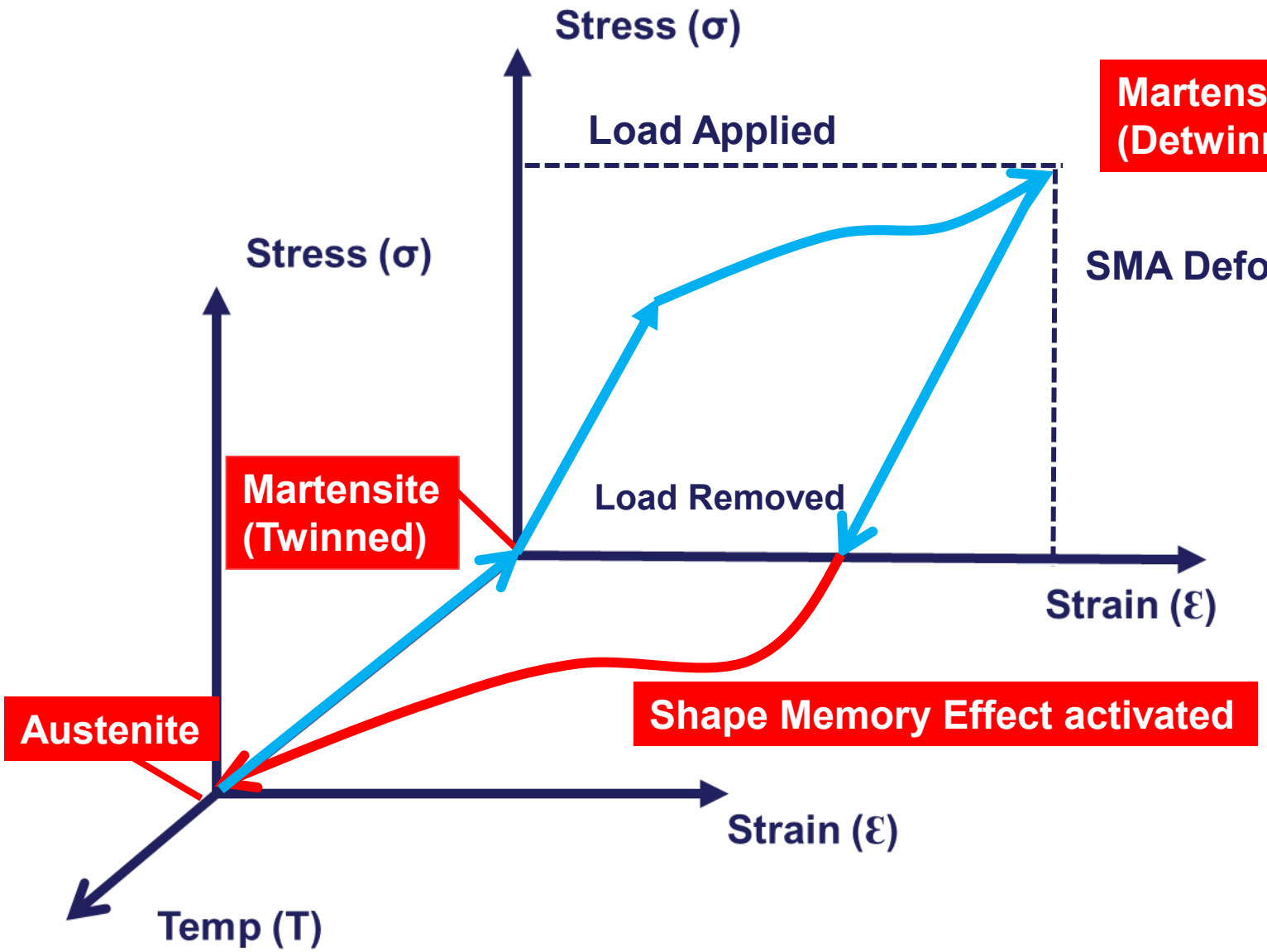




Delamination Crack Closure of SMA Tufts

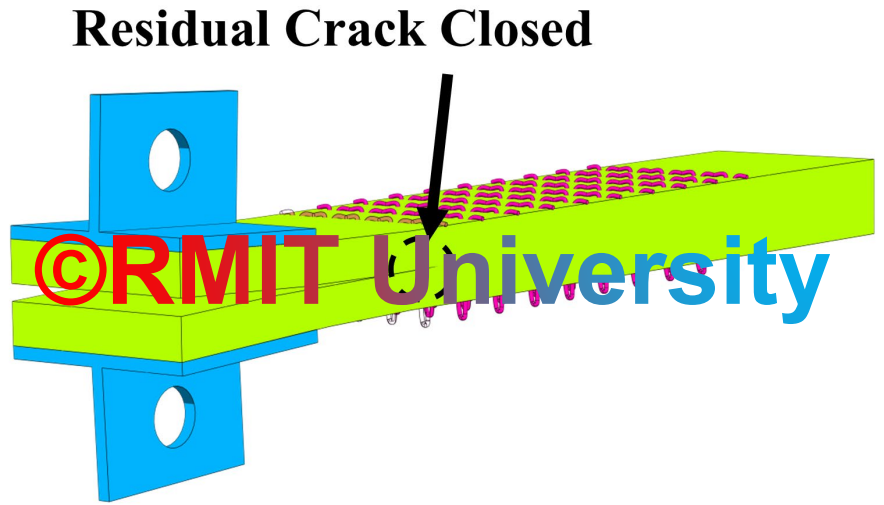


Delamination Crack Closure of SMA Tufts



Martensite (Detwinned)

SMA Deformed



Crack Closure Mechanism

- Shape Memory Effect (SME) of the SMA wires as tufts
- Phase transformation of the NiTi thermal SMA wire
- Repeatable process
- Strain recovery limit at 6-8%

Publication

- W. Khor, A. R. Ravindran, F. Ciampa, R. B. Ladani, **M. Limprapuwiwattana**, P. Whitton, A.D. Foreman, C. Meeks, A. Steele, T. Cooper, A. Rider, A.P. Mouritz (2023), "**Improving The Damage Tolerance Of Composite T-Joints Using Shape Memory Alloy Tufts"**, Composites Part A: Applied Science and Manufacturing 2023: p.107474

Acknowledgement

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What's next...