Interfacial Toughening of Hybrid Metal-Composite Joints Using 3D Printed Pins

By Tiana Bagnato

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Dr. Raj Ladani
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In collaboration with DSTG with approved DSI scholarship

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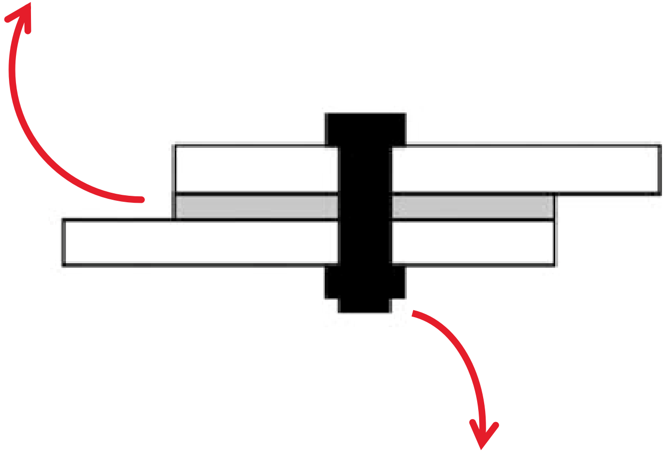
Adhesive

- Specific surface preparation
- Can fail catastrophically



Mechanical Fasteners

- Adds weight
- Damages composite

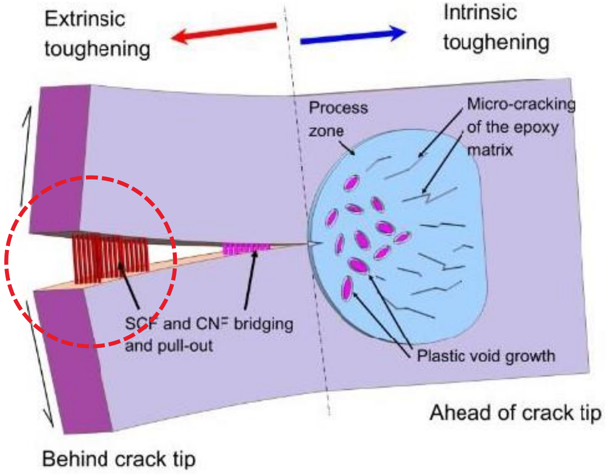


Figure 01. *Toughening mechanisms of reinforcements, Ravindran A.*

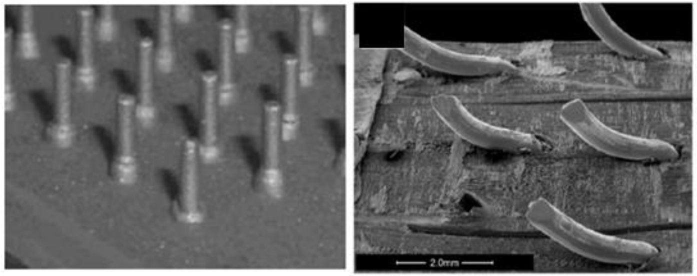


Figure 02. *Left; Steel CMT pins (Ucsnik S.), Right; Steel z-pins (Ravindran A.)*

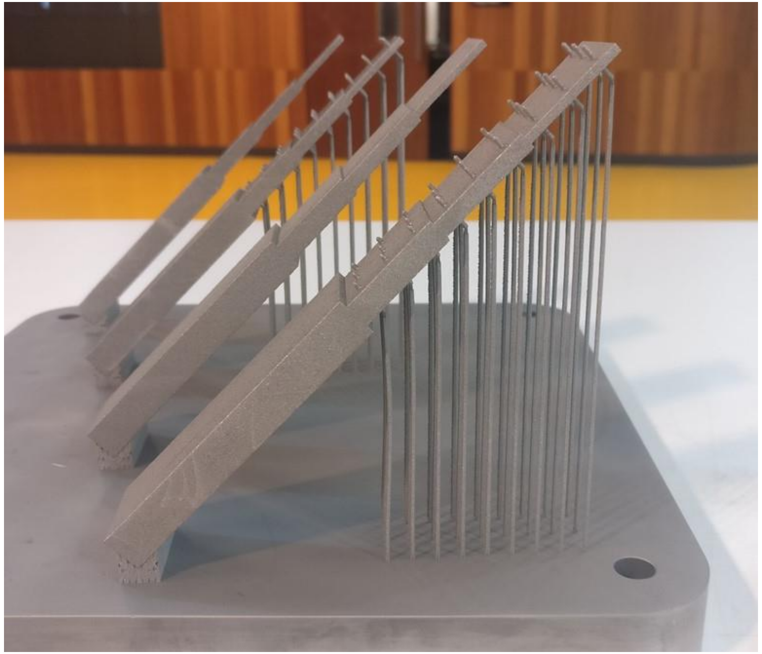


Figure 03. *3D printed titanium multi-step lap joints*

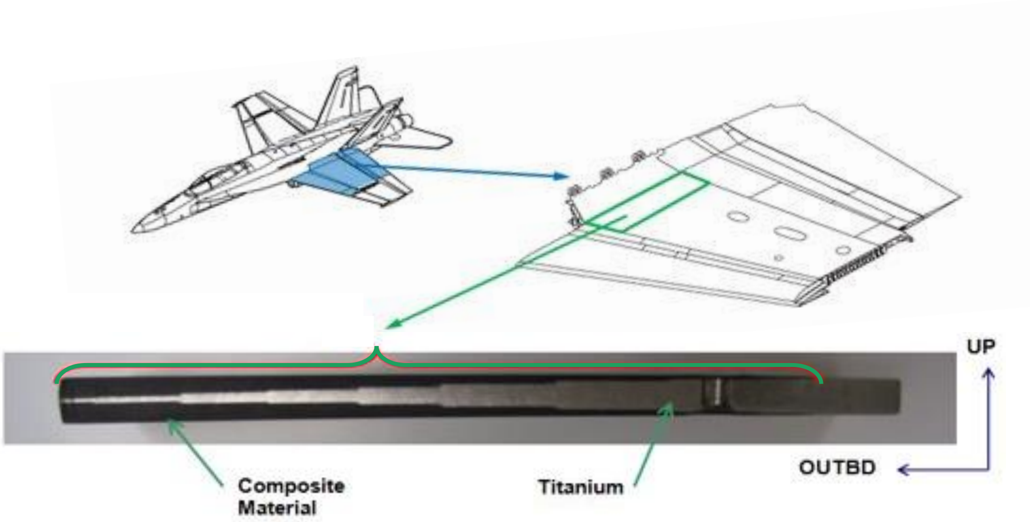


Figure 04. *F/A18A-D hybrid titanium-CFRP multi-step lap joint, Mouritz A. et al.*

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As-Manufactured Pin Features

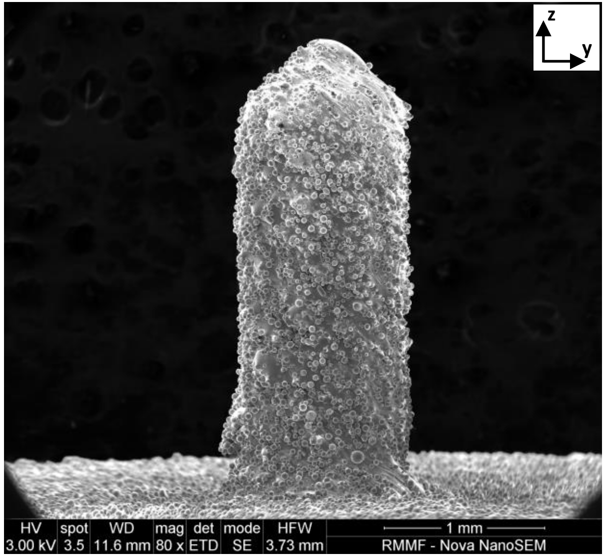


Figure 05. *SEM of as-manufactured SLM Ti-micro pin*

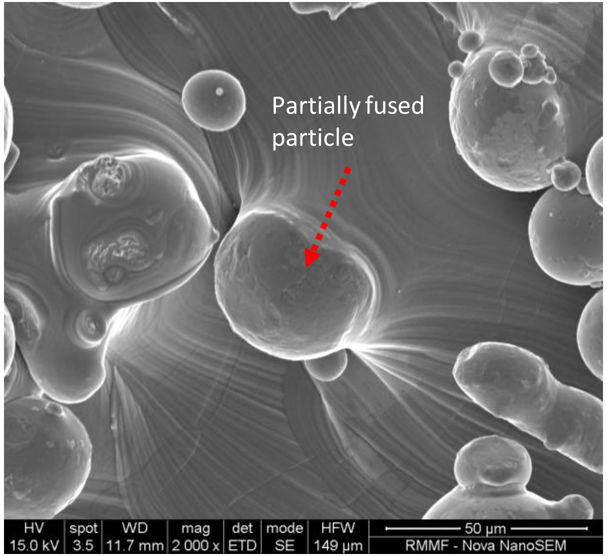


Figure 06. *High magnification SEM image of partially fused titanium particles*

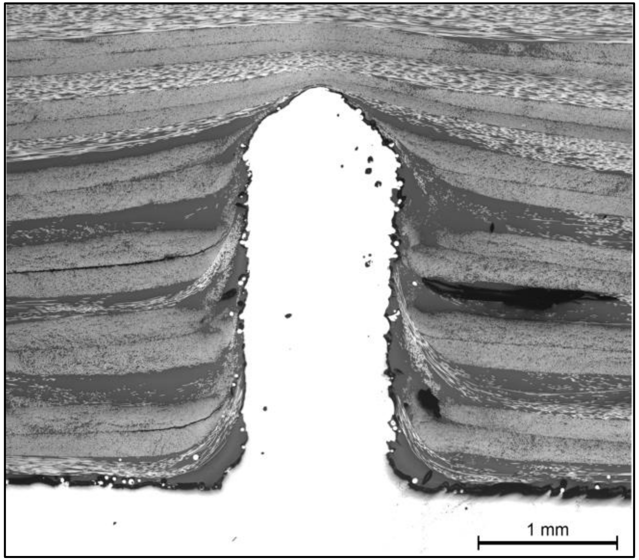


Figure 07. *Cross-section of in-situ micro pin*

- As-manufactured pin surface roughness: $7 \pm 0.75\mu m$
- CFRP experiences fibre crimping and eyelet formation

Mode I – Quasi-Static Testing

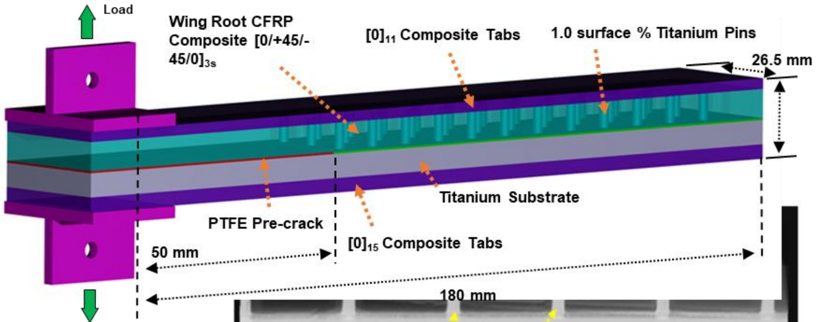


Figure 08. Schematic of mode I testing

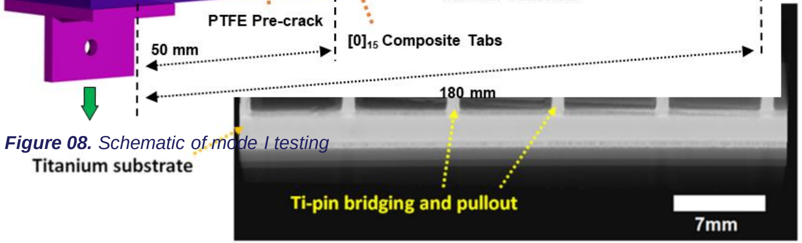
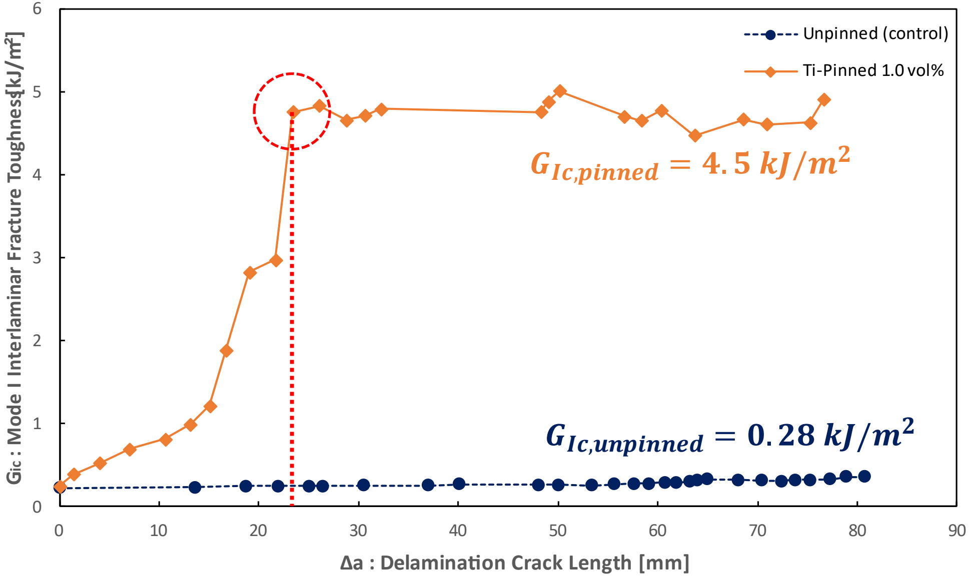


Figure 10. X-ray CT image of micro-pin bridging zone under mode I loading

Figure 09. R-curve of mode I testing results



- Improvement of ~1600% from unpinned to pinned specimen

Single Pin Pull-Out Testing

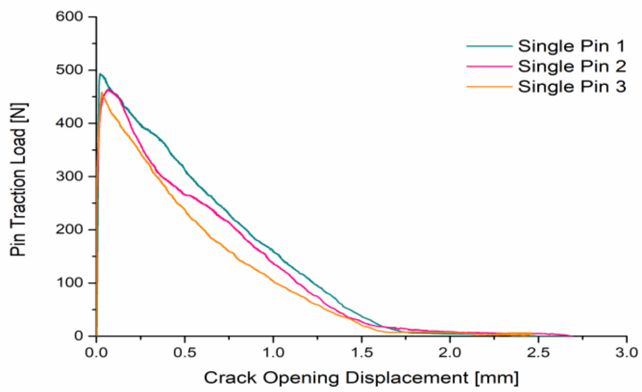


Figure 11. *Pin traction load vs crack opening displacement results*

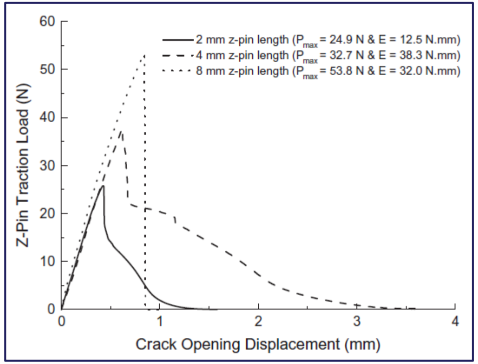


Figure 13. *Typical Z-Pin traction load vs displacement graph, Mouritz et al.*

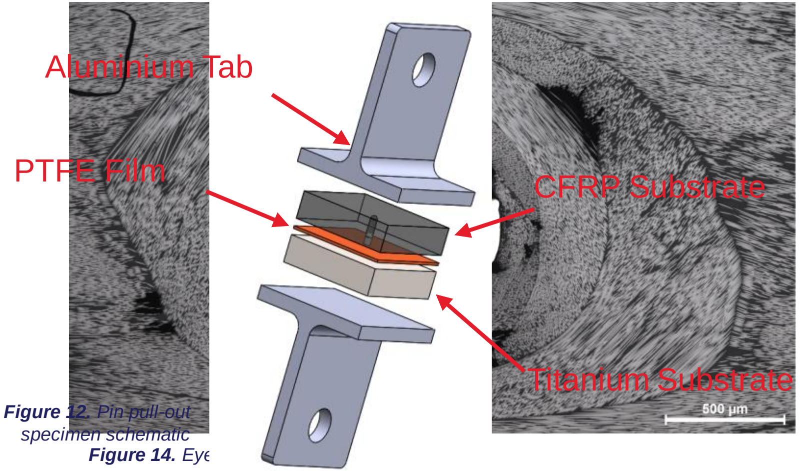


Figure 12. *Pin pull-out specimen schematic*

Figure 14. *Eye*

- Average peak load and pull-out traction energy; 472N and 337 N.mm respectively
- CTE values, pull-out results and optical microscopy imaging suggest the pin is entirely debonding from the surrounding matrix

Mode II – Quasi-Static Testing

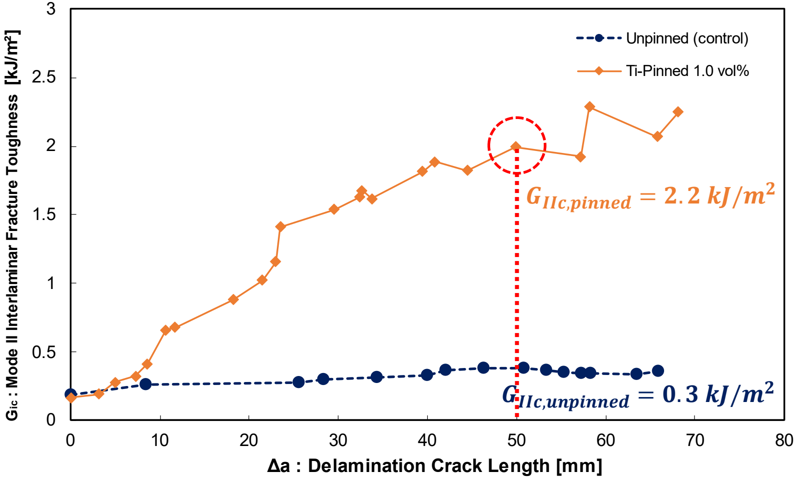
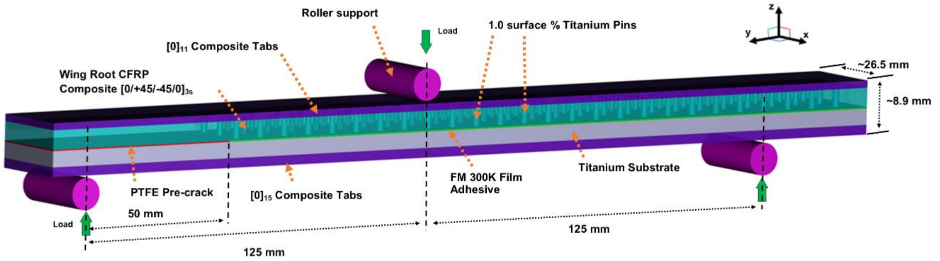


Figure 15. *R-curve of mode II testing results*

Figure 16. *Schematic of mode II testing*



- Improvement of ~500% from unpinned to pinned specimen

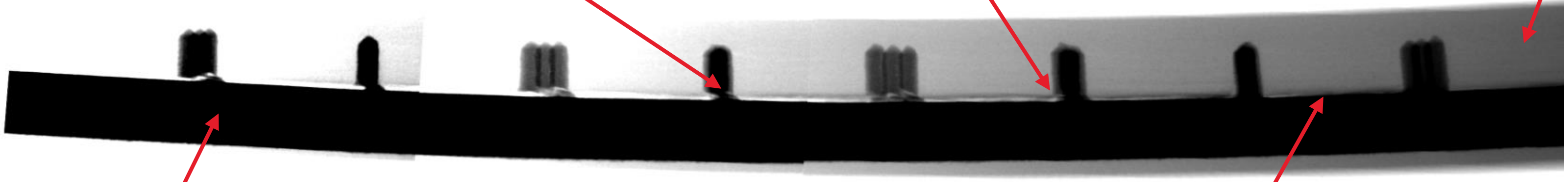


Figure 17. *X-ray CT scan of progressive pin failure under mode II*

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Interlaminar Fatigue – Mode I

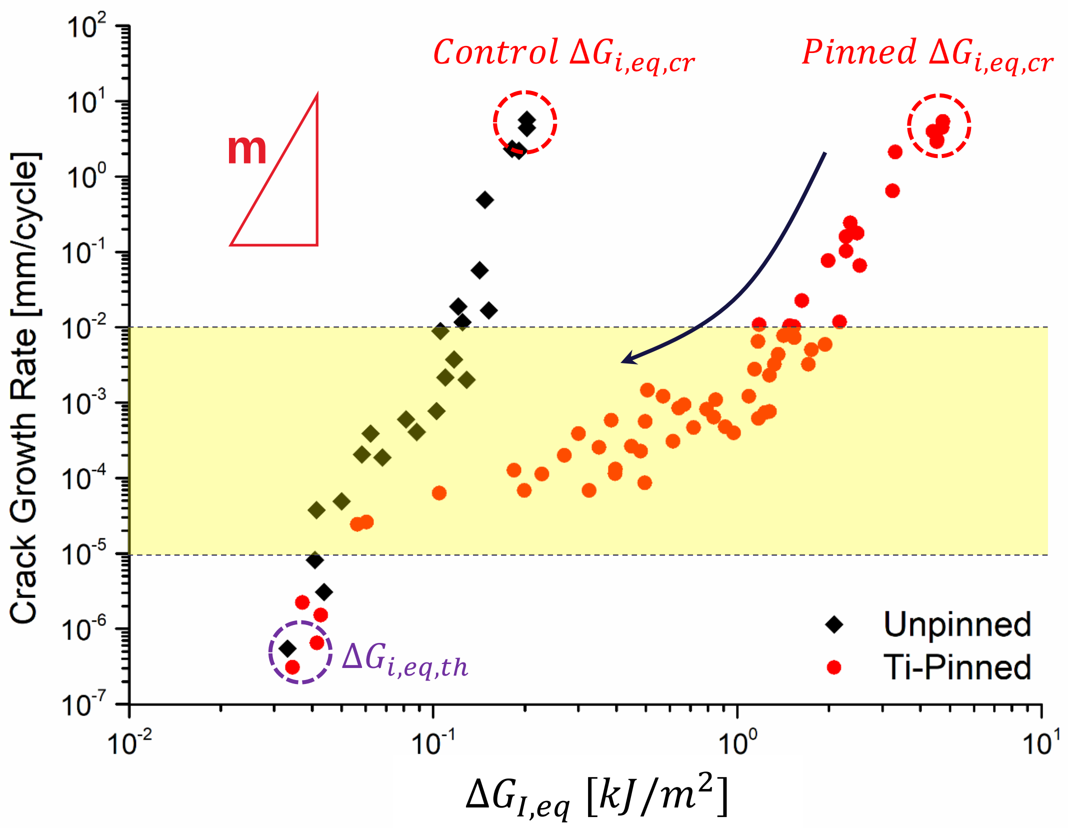


Figure 17. *Paris-like curve of mode I interlaminar fatigue results*

- R-ratio of 0.1 at 5 Hz
- Load shedding scheme
- $m_{unpinned} = 5.343$
- $m_{Ti-pinned} = 0.833$

Interlaminar Fatigue – Mode I

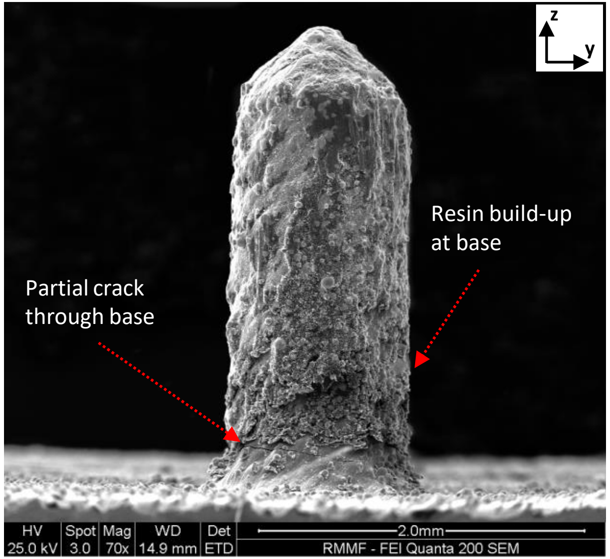


Figure 18. *SEM image of Ti-pin after mode I fatigue testing*

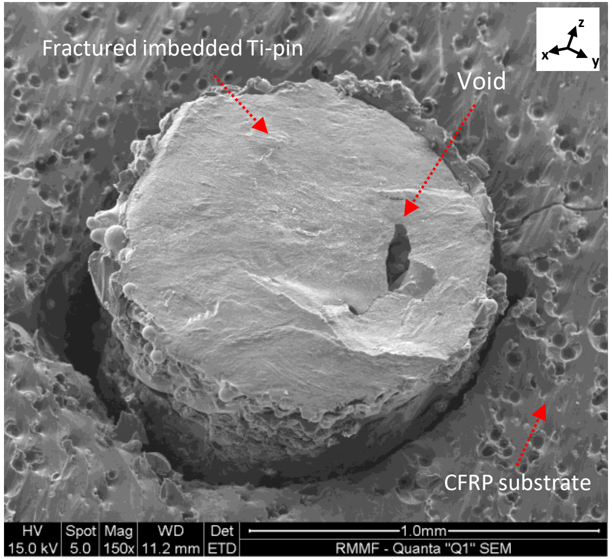


Figure 19. *SEM image of fractured Ti-pin embedded in CFRP laminate*

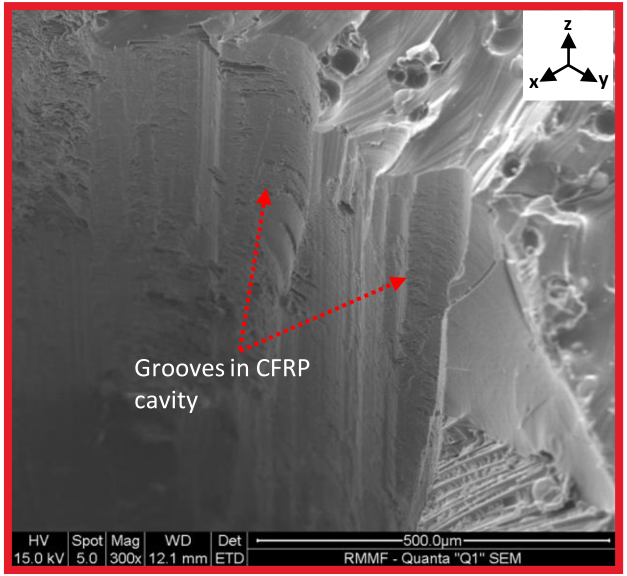


Figure 20. *High magnification SEM image of CFRP cavities*

- Pin undergoes large tensile and compressive loads
- Gradual pin fracture further resists interlaminar cracking
- Widening of CFRP grooves worsens through-out test

Interlaminar Fatigue – Single Pin Pull-Out

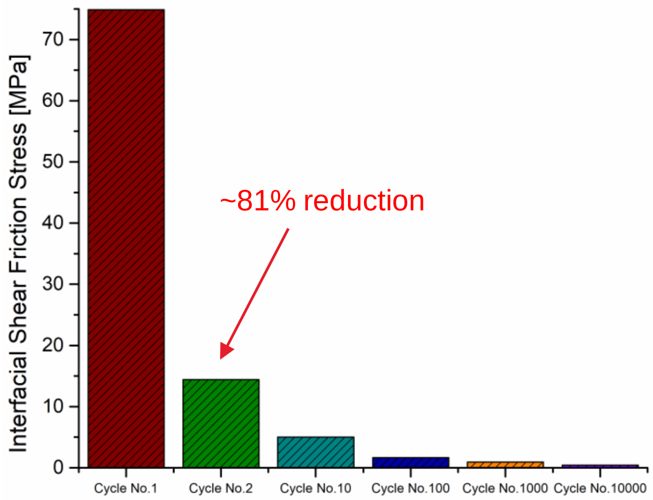


Figure 21. *Interfacial shear friction stress bar chart*

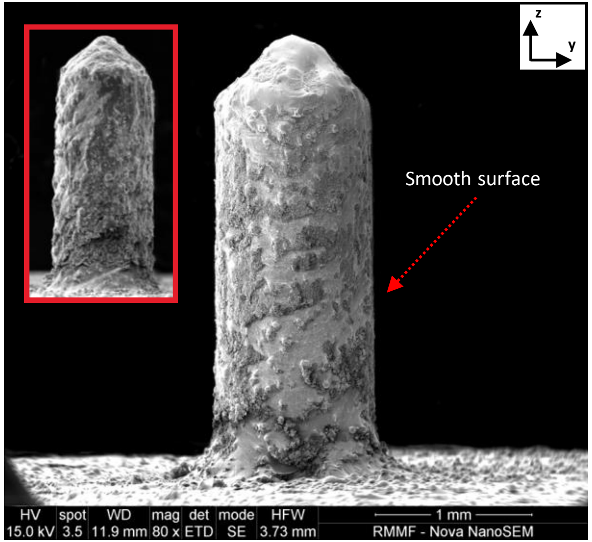


Figure 22. *SEM image of single pin pull-out fatigue Ti-pin after 30 000 cycles (boxed: Mode I fatigue pin)*

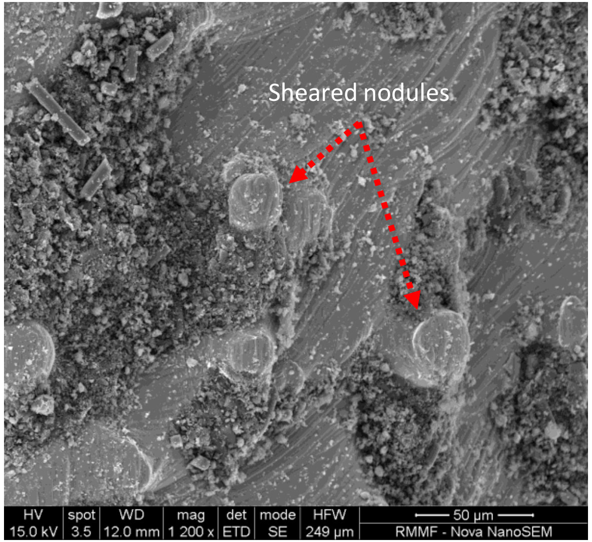


Figure 23. *High magnification SEM image of sheared titanium nodules*

Interlaminar Fatigue – Mode I

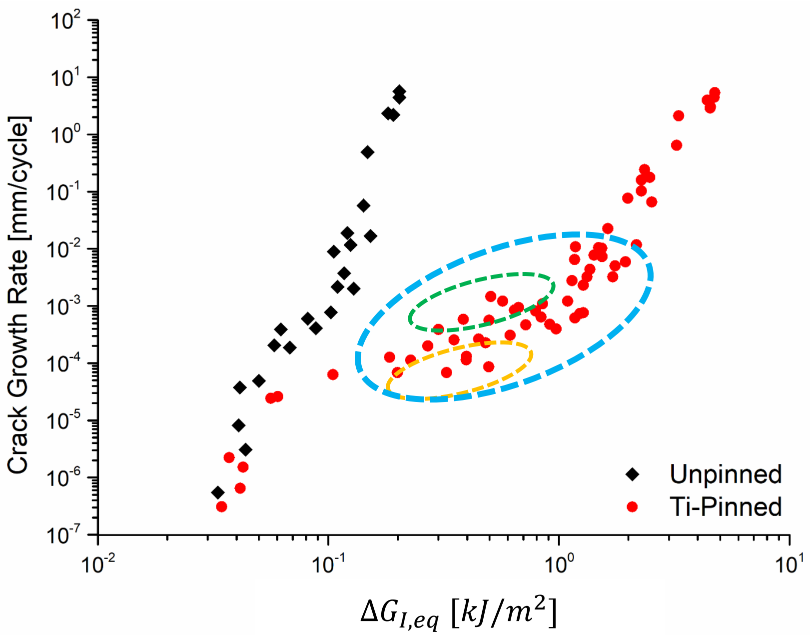


Figure 24. *Mode I fatigue fracture between rows of pins*

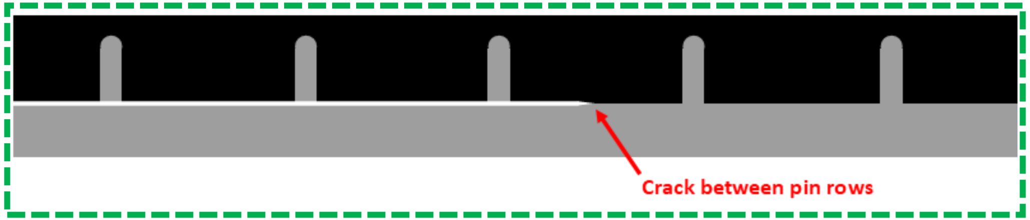
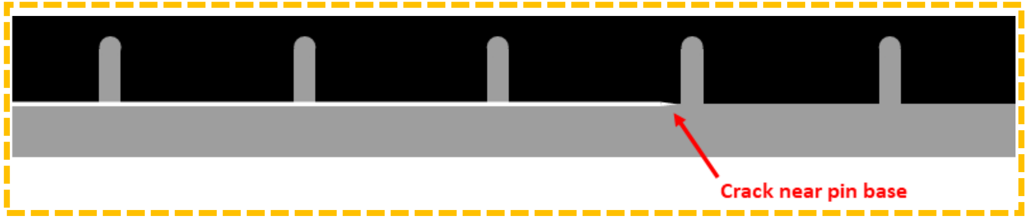


Figure 35. *Mode I fatigue fracture at pin row*



- Larger crack growth rate at given strain energy release rate for crack location between pins
- Smaller crack growth rate at given strain energy release rate for crack location at pin row

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Interlaminar Fatigue – Mode II

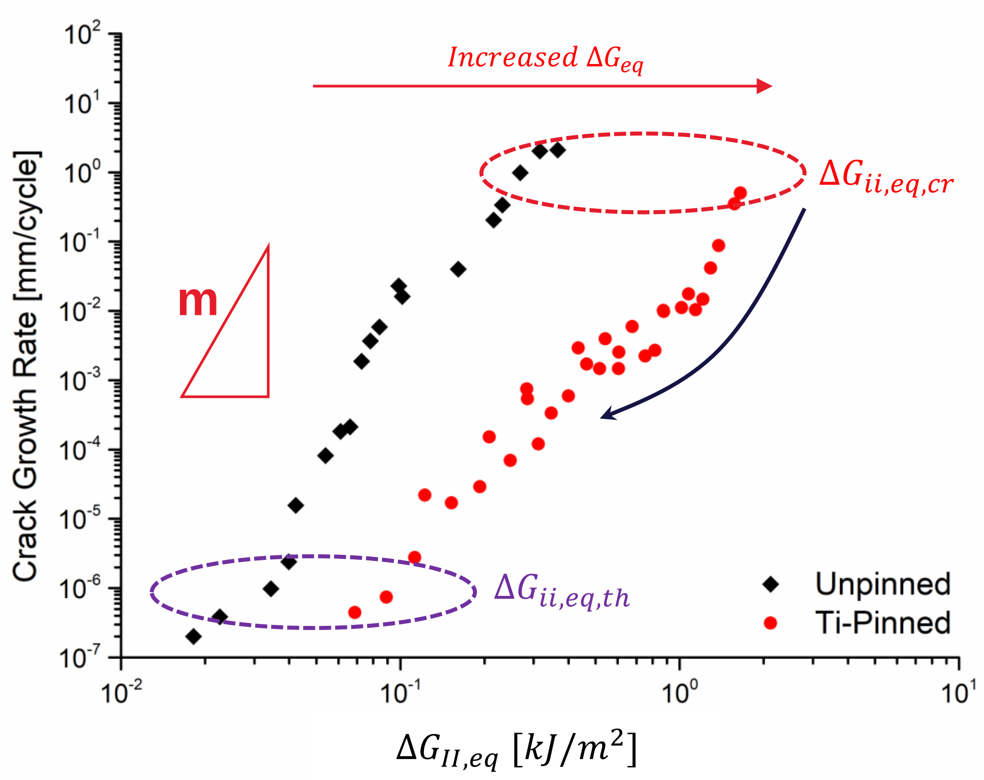

Figure 26. Paris-like curve of mode II interlaminar fatigue results

- R-ratio of 0.1 at 5 Hz
- Load shedding scheme
- $\uparrow \Delta G_{II,eq,th} \approx 167\%$
- $m_{unpinned} = 2.622$
- $m_{Ti-pinned} = 2.008$

Interlaminar Fatigue – Mode II

Figure 27. *Ti-pin embedded in CFRP laminate; high SERR region*

Figure 28. *Ti-pin embedded in CFRP laminate; low SERR region*

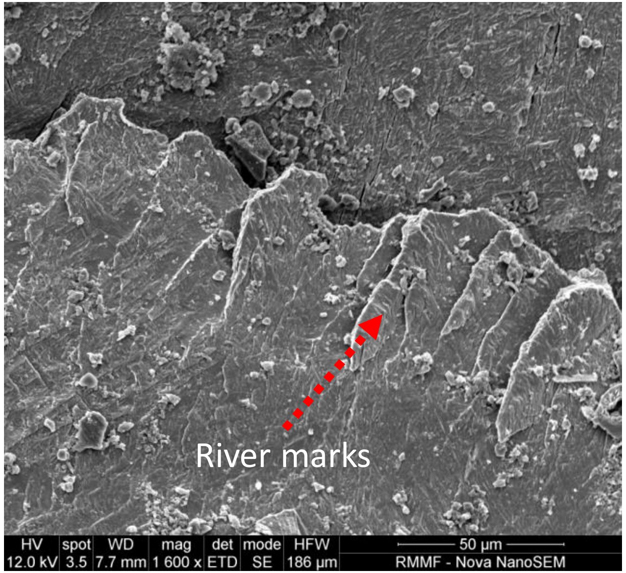

Figure 29. *High magnification SEM image of river marks*

- Plasticisation of pins under shear → absorbing energy from crack front
- River marks evident showing crack progression and direction

Interlaminar Fatigue – Mode II

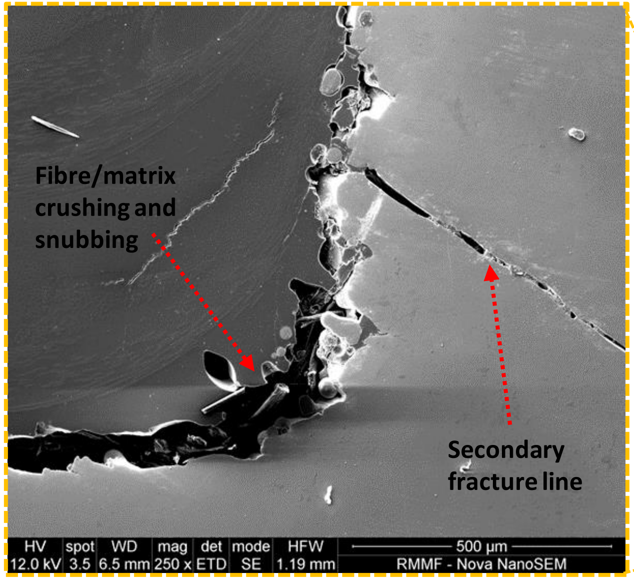

Figure 30. High magnification SEM image of secondary fracture line and snubbing

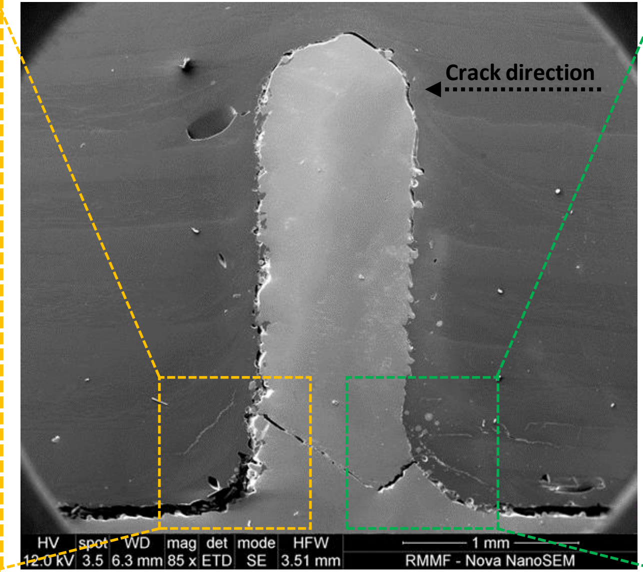

Figure 31. SEM cross sectional image of mode II pin fracture

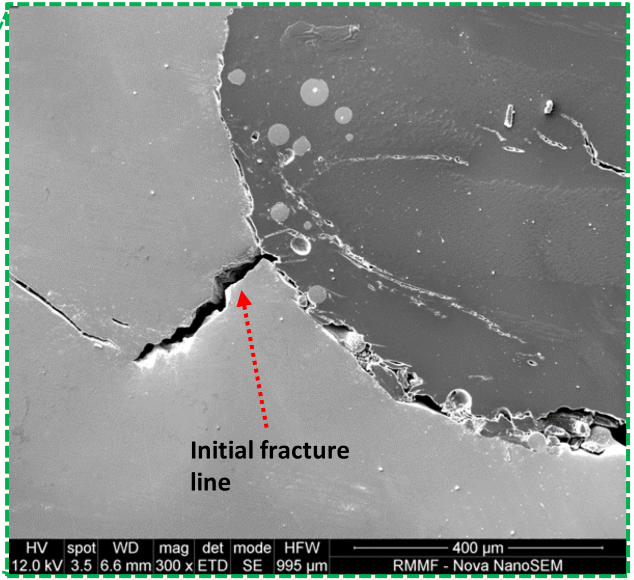

Figure 32. High magnification SEM image of initial fracture line

- Pin fracture captured in two stages
- Fracture propagates along print plane upon pin weakening
- Snubbing absorbs energy from crack front

Summary

- Improvement of interlaminar fracture in the pinned joints is higher under mode I due to bridging zone formation
- Mode I fatigue fraction resistance is mainly due to the lateral pressing of pins on CFRP wall
- Mode II fatigue fracture resistance is mainly due to 2-stage pin fracture as well as fibre/matrix crushing and snubbing

Further information on research:

- Bagnato et al.,*“Superior interfacial toughening of hybrid metal-composite structural joints using 3D printed pins”*, Composites Part A
- “Interfacial fatigue performance of hybrid titanium-composite joints reinforced with 3d printed pins” – Undergoing review

Acknowledgments

Supervisory team:

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Assoc. Prof Everson Kandare
Dr. Raj Ladani
Dr. Anil Ravindran

DSTG Representatives:

Dr. John Wang
Dr. Paul Chang

DSTG and DSI Scholarship representatives
Composites lab team
Materials and structures lab team

Thank you for listening

Questions are welcome!