The University of Texas at Austin
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JACOBS SCHOOL OF ENGINEERING

In-Situ Consolidated Automated Fiber Placement Carbon Fiber PAEK Composites

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Motivated Towards a Sustainable Composite Industry

Energy Expensive, Slow

& Non-Recyclable

?

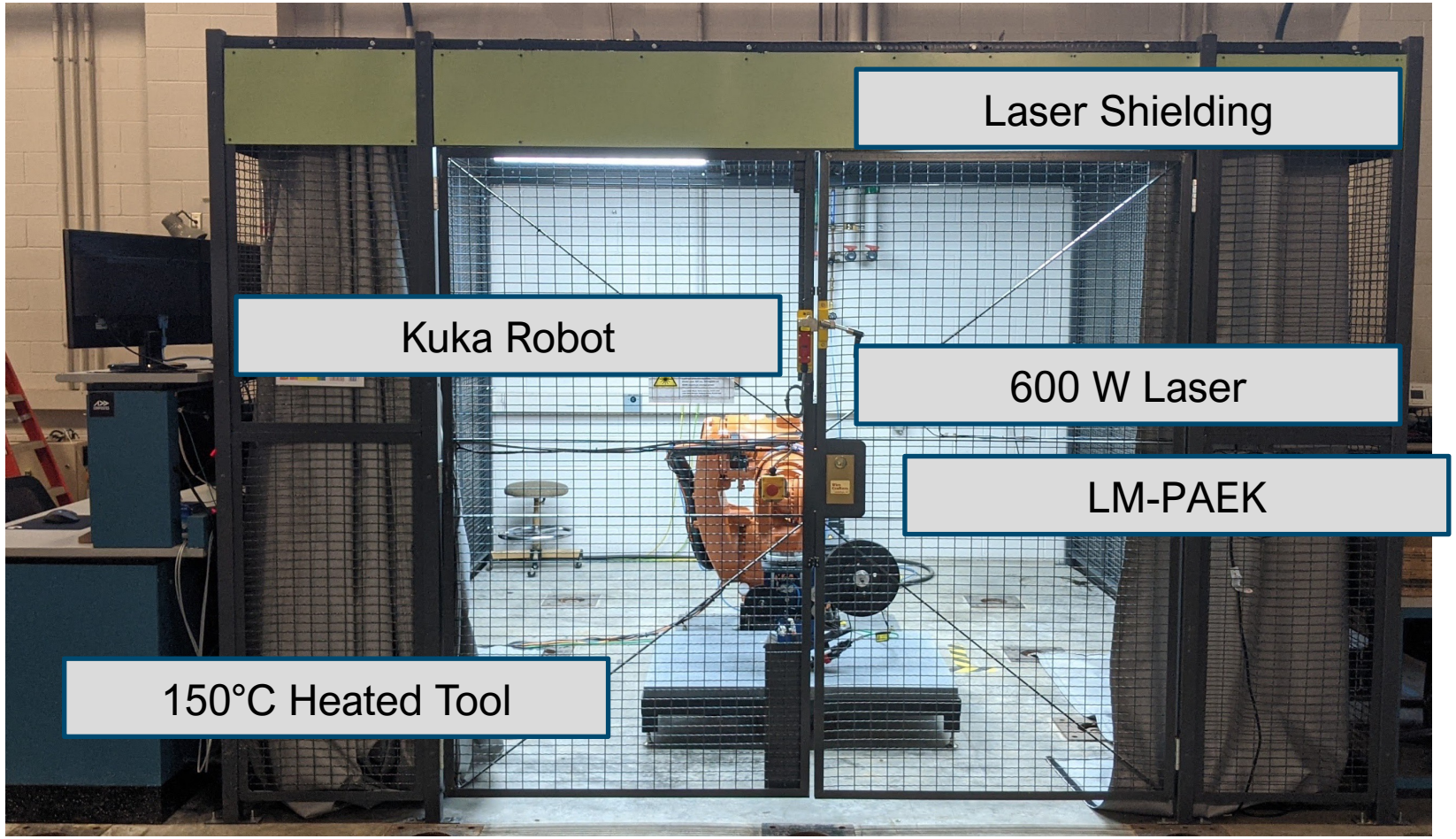
High-Rates, Tough &

Sustainable End-of-Life

Outline

- In situ Consolidation AFP of Thermoplastic Composites (ICAT)
  - Overview of our system
  - Bond strength and fracture toughness in ICAT
  - Effect of tape staggering on interlaminar strength
  - Towards understanding bonding in ICAT: a materials science view
  - Conclusions

Laser-Assisted Automated Fiber Placement (L-AFP)
In situ Consolidation AFP of Thermoplastic Composites (ICAT)

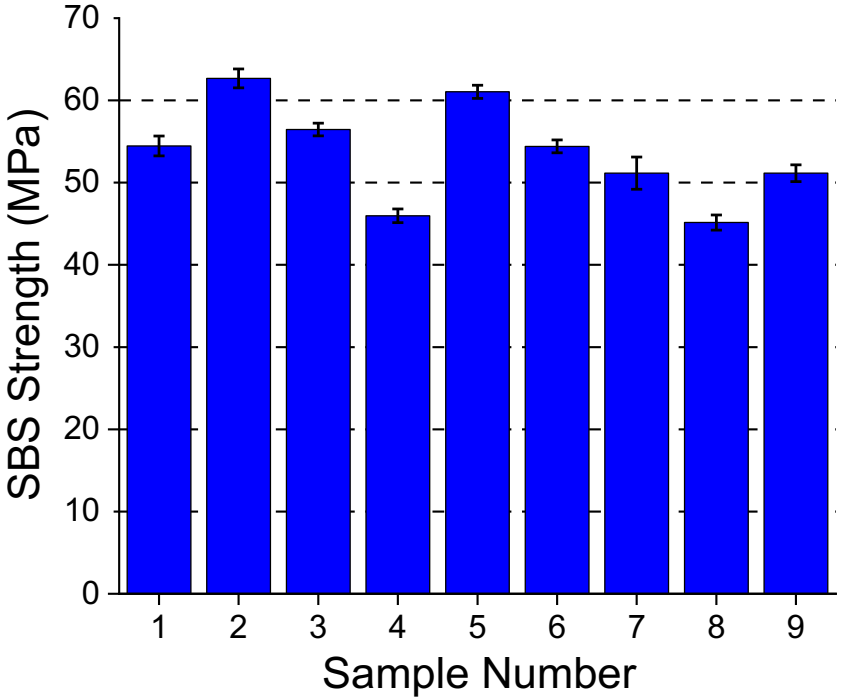


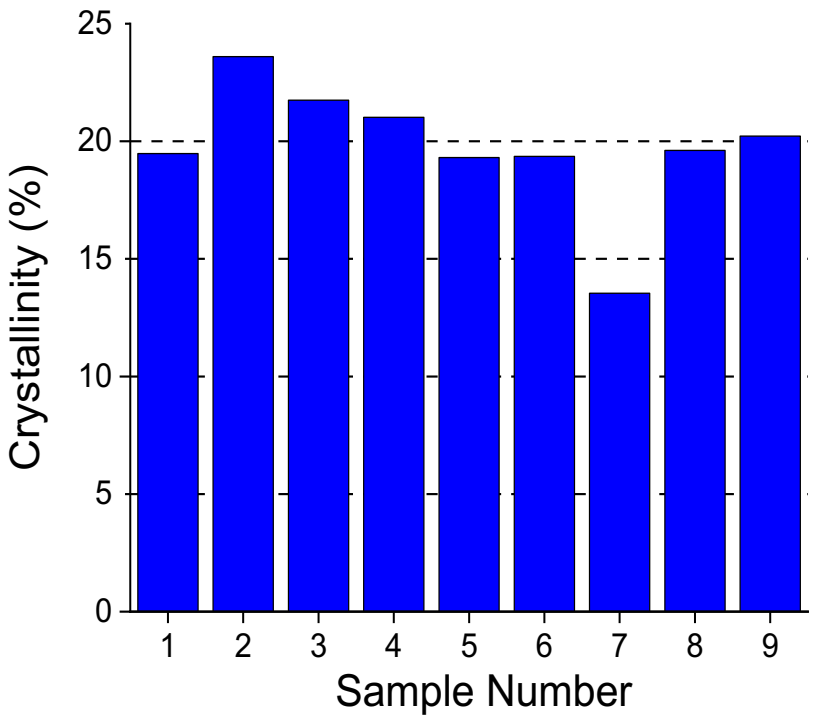
ICAT Processing-Structure-Properties

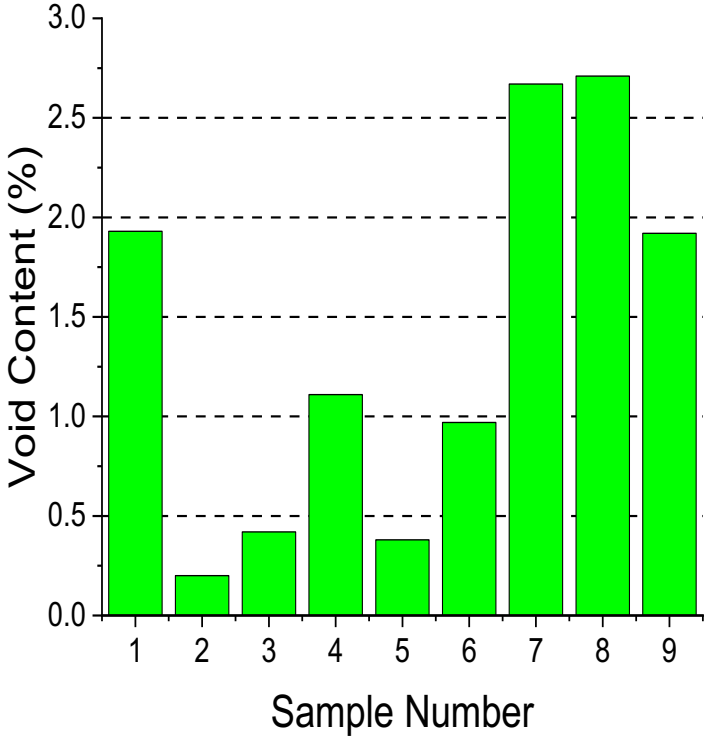
- Process variables: speed, temperature, compaction force
- Three factors per variable
- Short beam shear strength as response
- Nine samples for the partial factorial design of experiments
- Taguchi method analysis

Sample	*Speed (mm/s)*	*Processing Temp. (˚C)*	*Compaction Force (N)*
#1	50	360	200
#2	50	400	300
#3	50	380	400
#4	100	360	300
#5	100	400	400
#6	100	380	200
#7	150	360	400
#8	150	400	200
#9	150	380	300

Results (1/2” tapes, no gaps)

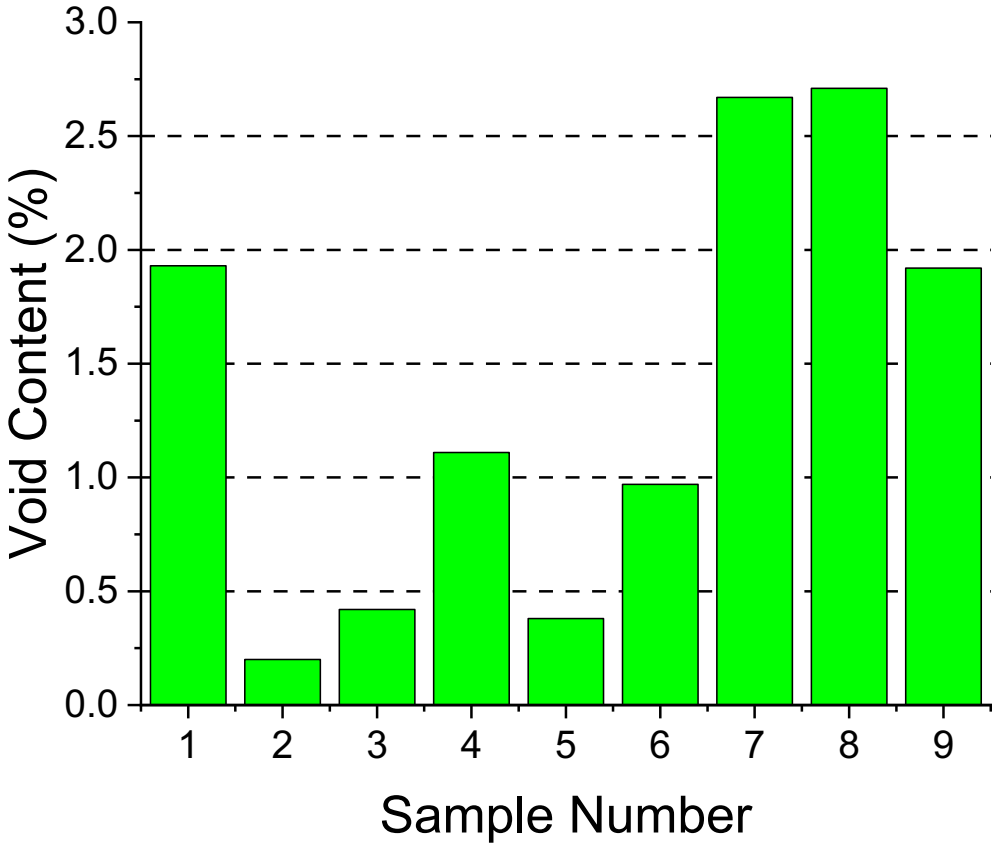


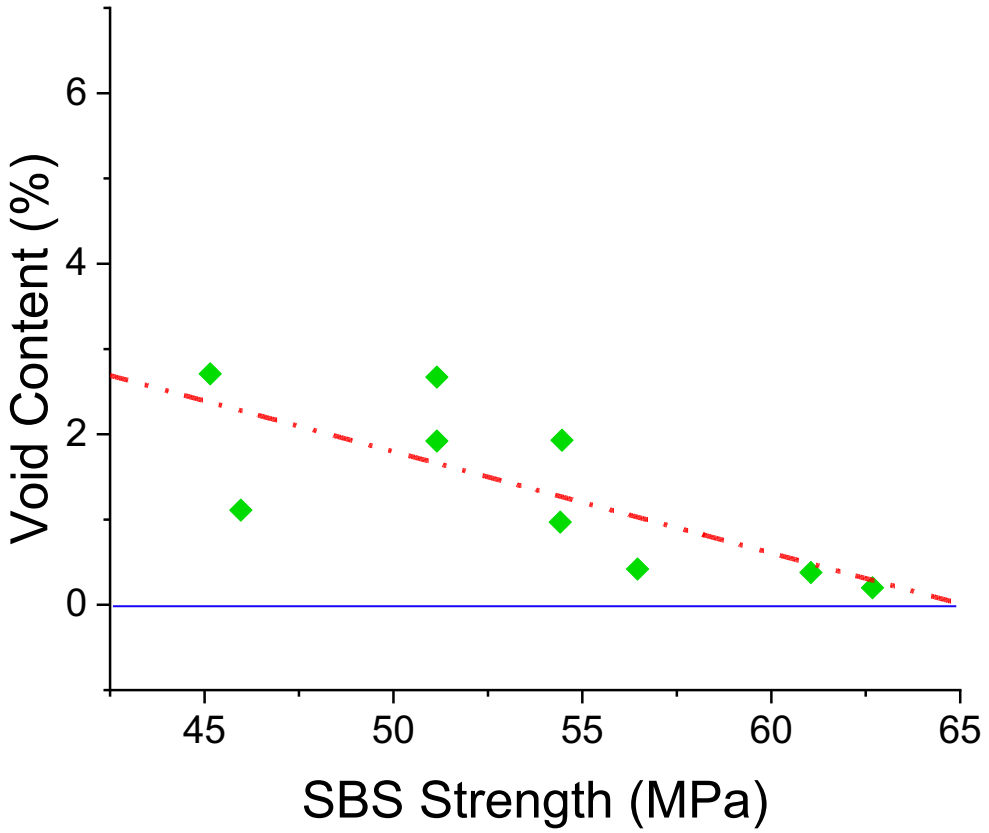




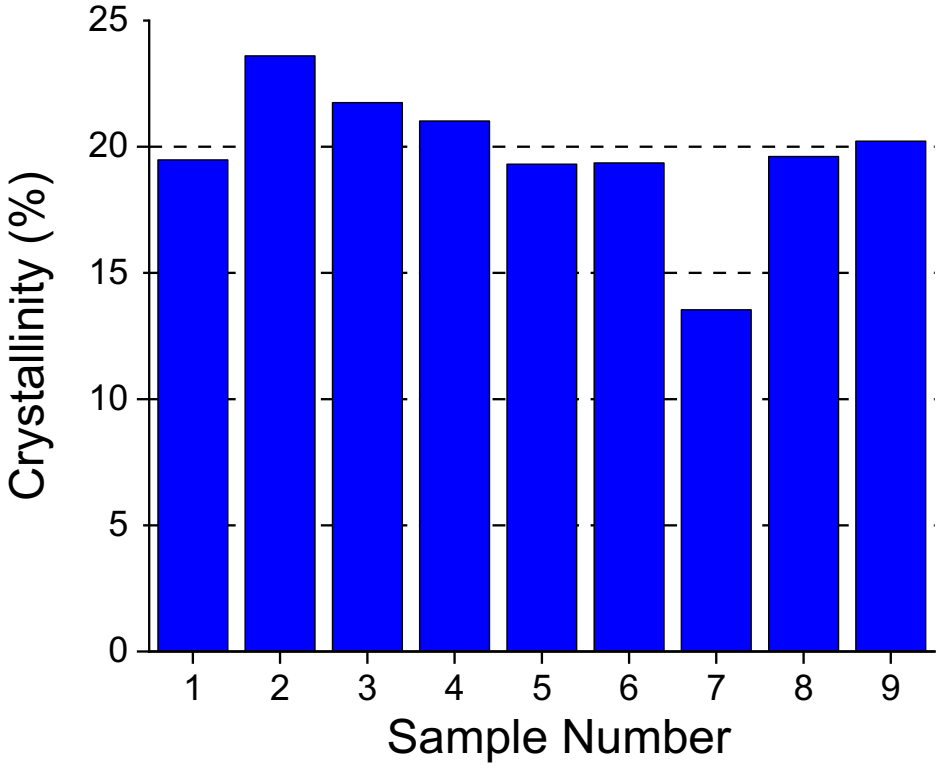
Sample	*Speed (mm/s)*	*Processing Temp. (˚C)*	*Compaction Force (N)*
#2	50	400	300
#7	150	360	400

Void Analysis





Crystallinity analysis



Sample	*Speed (mm/s)*	*Processing Temp. (˚C)*	*Compaction Force (N)*
#2	50	400	300
#7	150	360	400

Post-annealed samples achieve a crystallinity of ~25% and SBS strength of 63 MPa.

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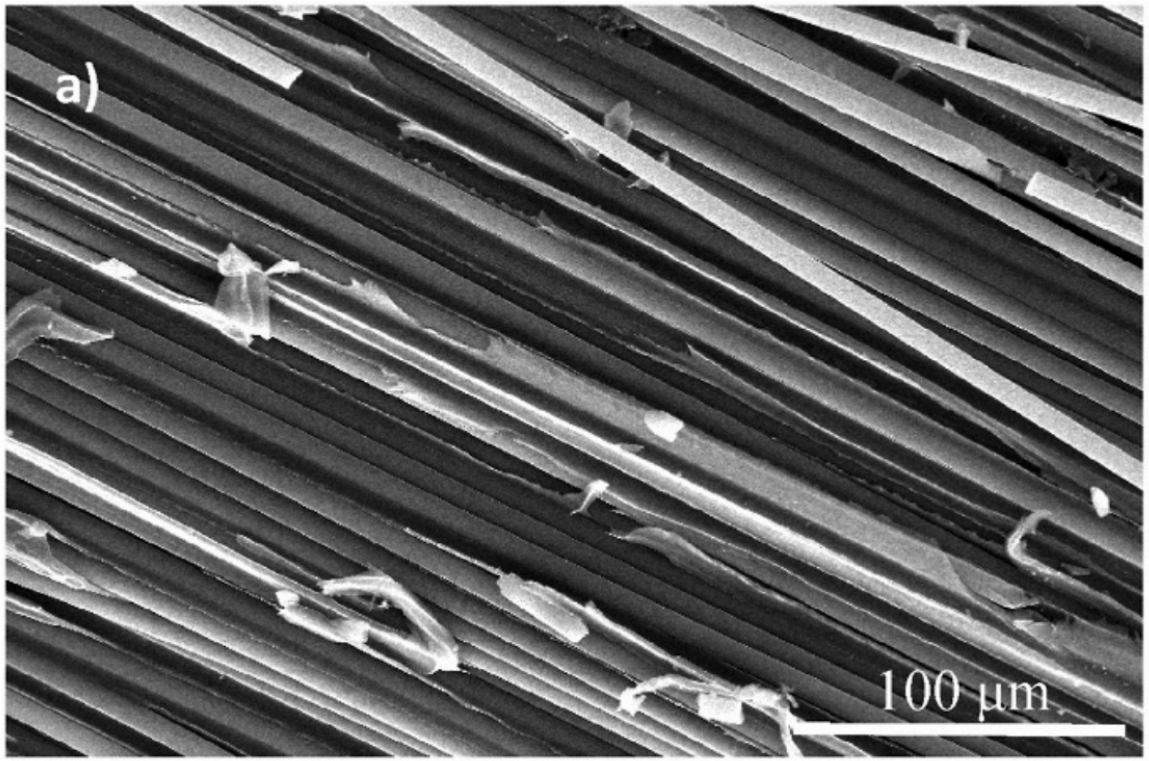
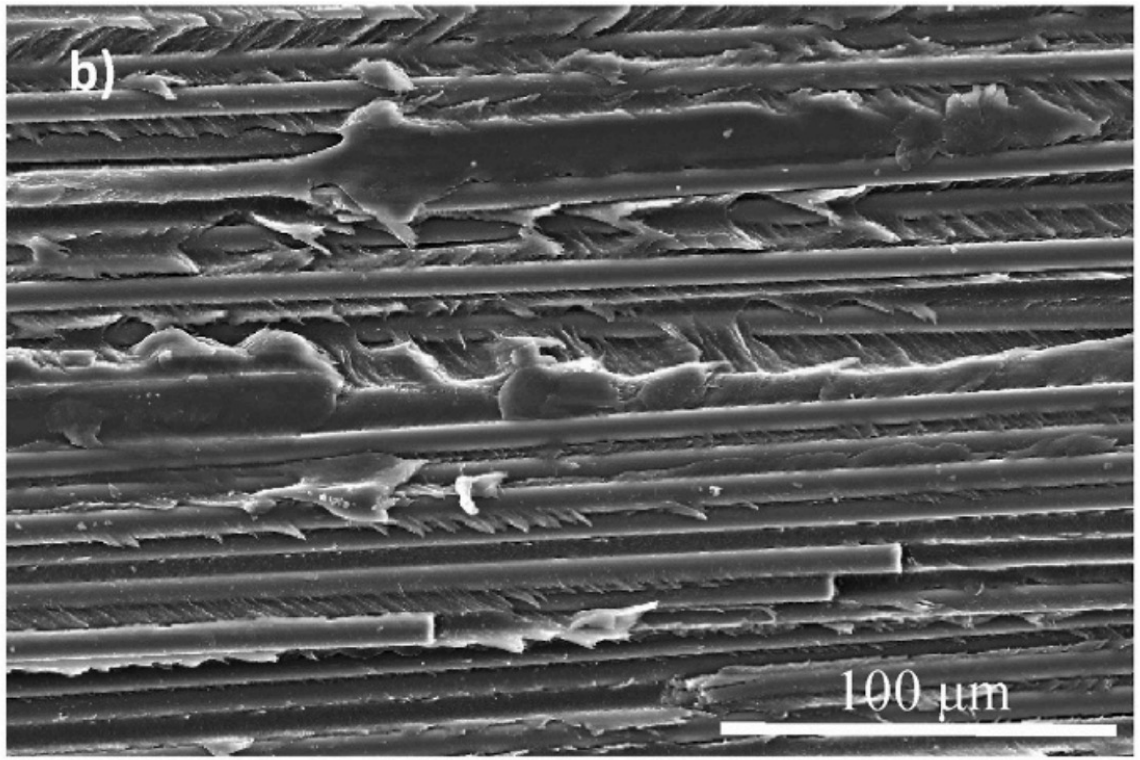
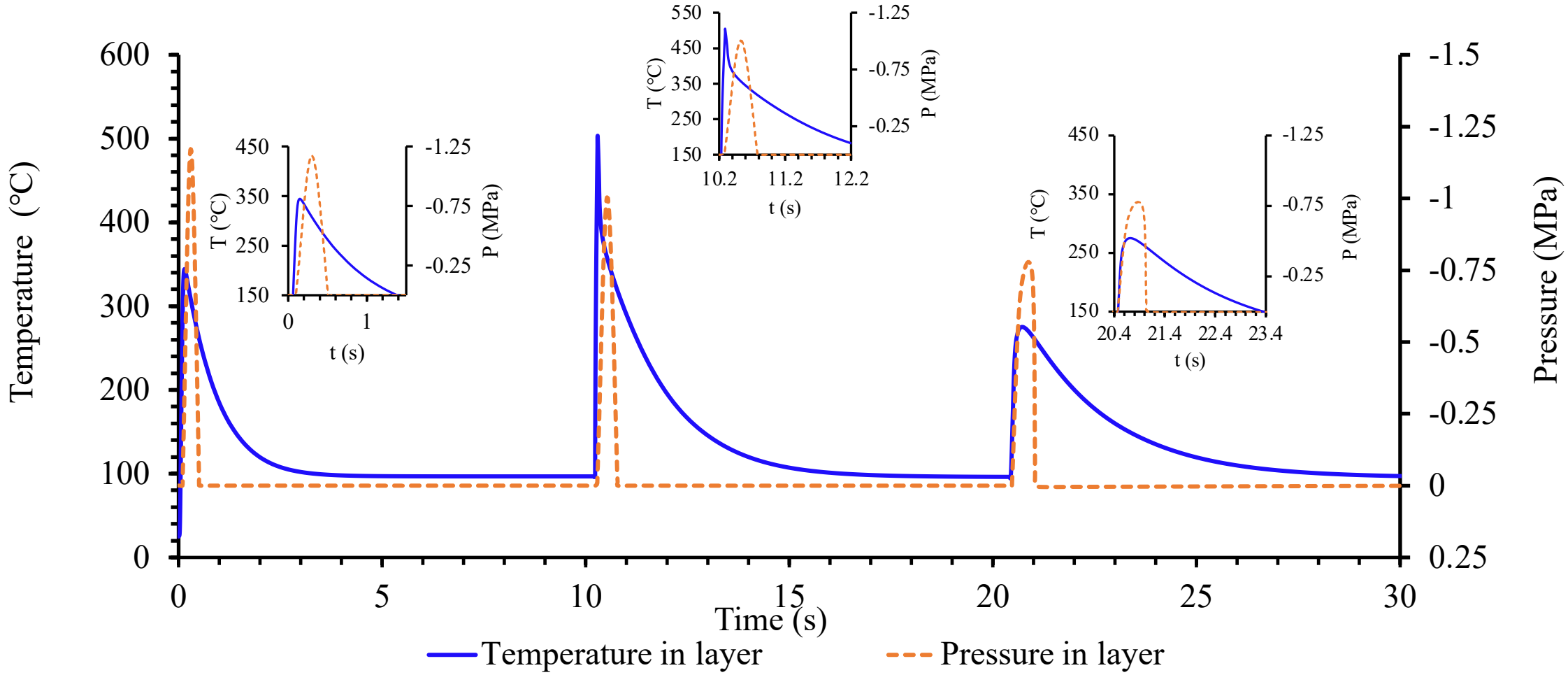
Failure Modes:
ICAT vs. Compression Molded





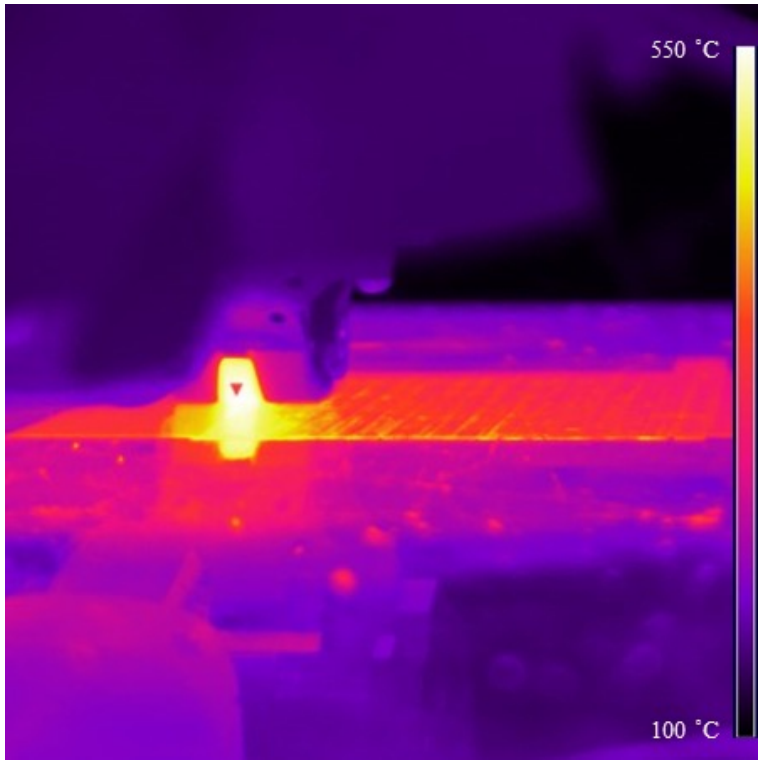
Repetitive Heating and Pressing



Fracture Toughness Coupons

Processing Parameters

- Speed: 100 mm/s, 200 mm/s
- Processing Temperature: 400 °C
- Compaction force: 400 N
- Heated Tool: 150 °C
- Material: CF/LM-PAEK Tape 12.35 x 0.13 mm



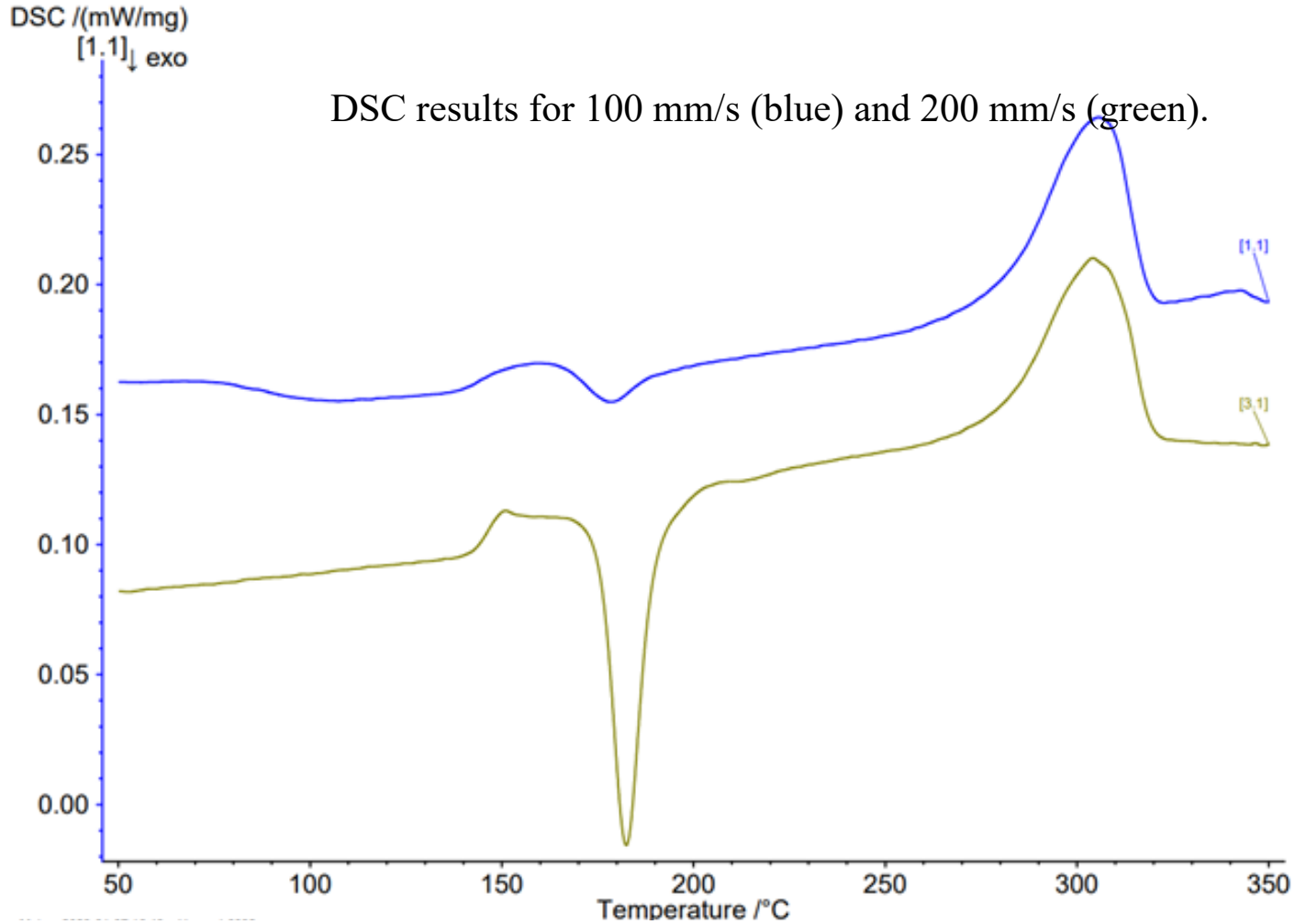
Fracture Toughness sample fabrication

Solidification Kinetics

Crystallinity of

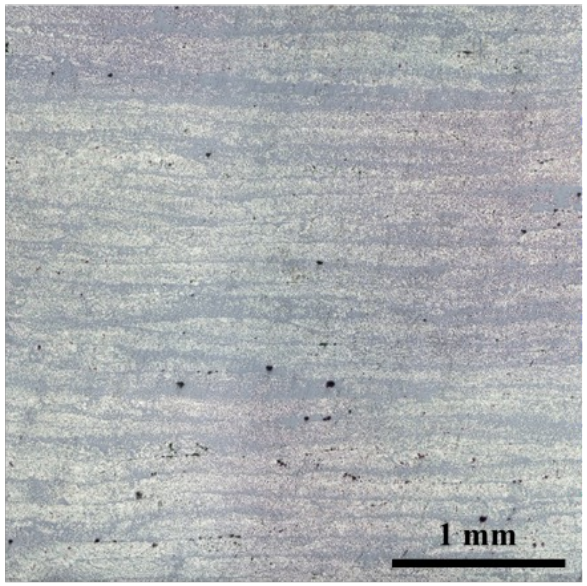
- 100 mm/s ICAT: 23%
- 200 mm/s ICAT: 9%

Tool temperature at 150 °C

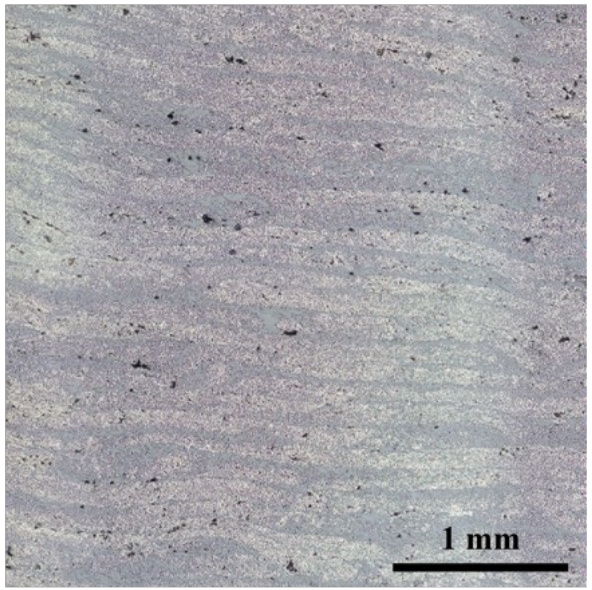


DSC results for 100 mm/s (blue) and 200 mm/s (green).

Void Content and Shape

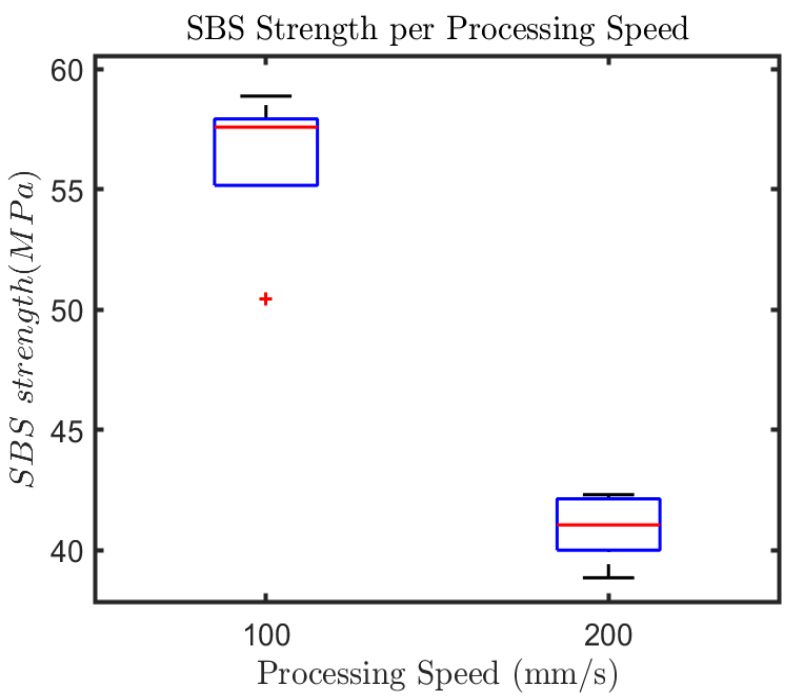


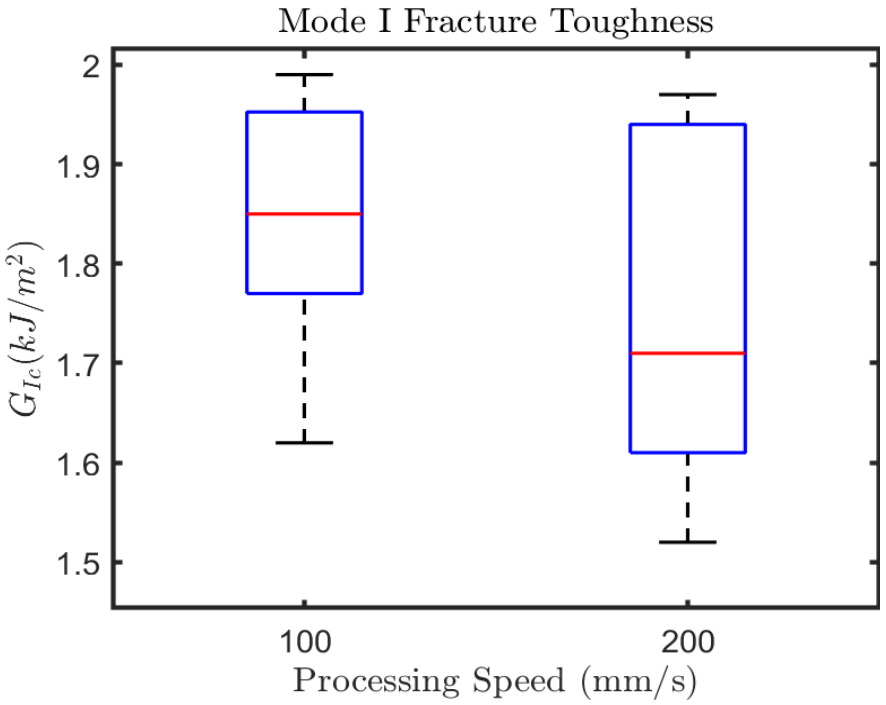
SBS coupons 100 mm/s

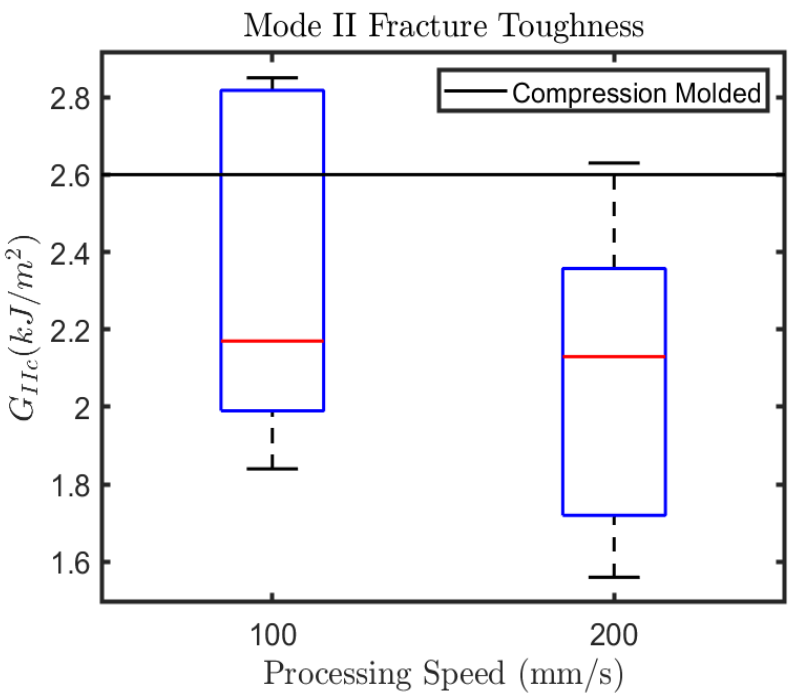


SBS coupons at 200 mm/s

ILSS, G_{IC}, and G_{IIC}







SBS for post-processed samples:
VBO and CM is ~95 MPa

G_{IC} and G_{IIC} for Different Composites (DCB and ENF)

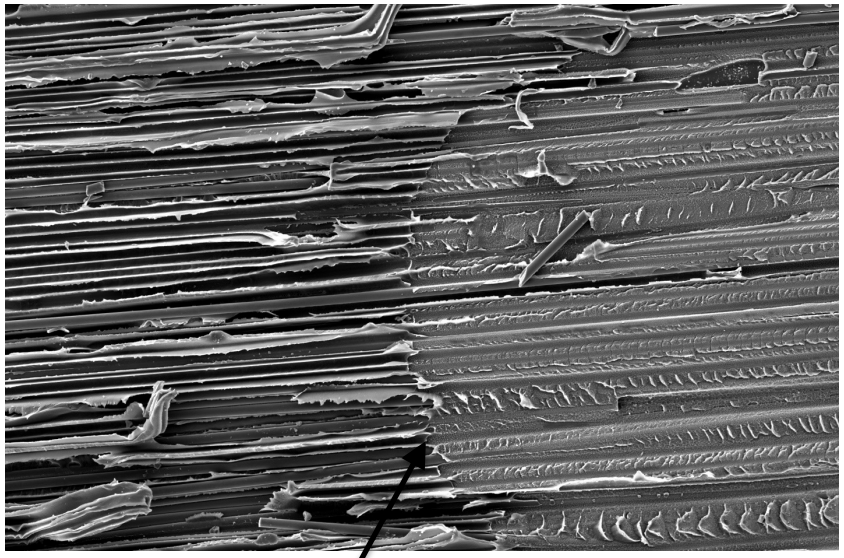
Strain Energy Release Rate in $KJ.m^{-2}$

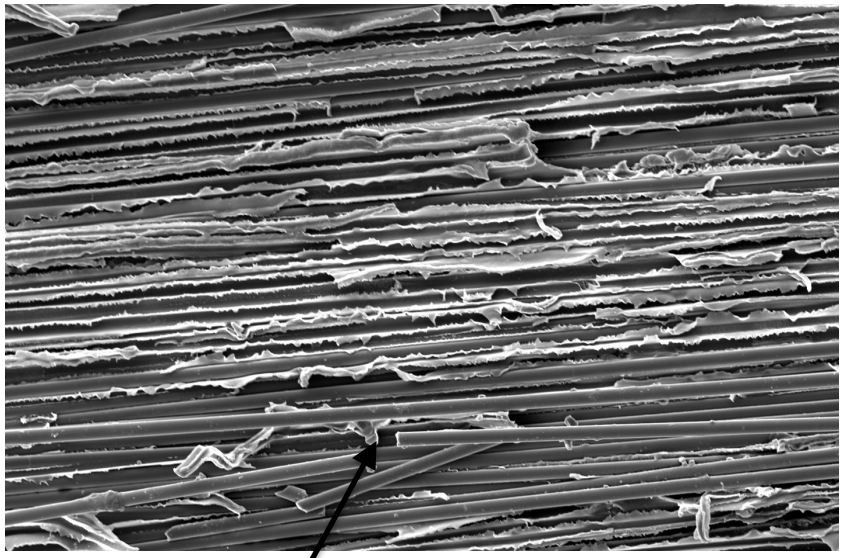
Material	G_{Ic}	G_{IIc}
ICAT (0.2 m/s or ~500 IPM)	**1.7**	**2.1**
T300/914	0.2	0.5-0.6
AS4/3502	0.2	0.6
AS4/PEEK	1.3-1.7	1.2-1.8
AS4 Fabric/LY564	0.72	3.5
IM7/8552	0.2	1.1-1.7

Fractography of Mode I Coupons

100 mm/s

200 mm/s





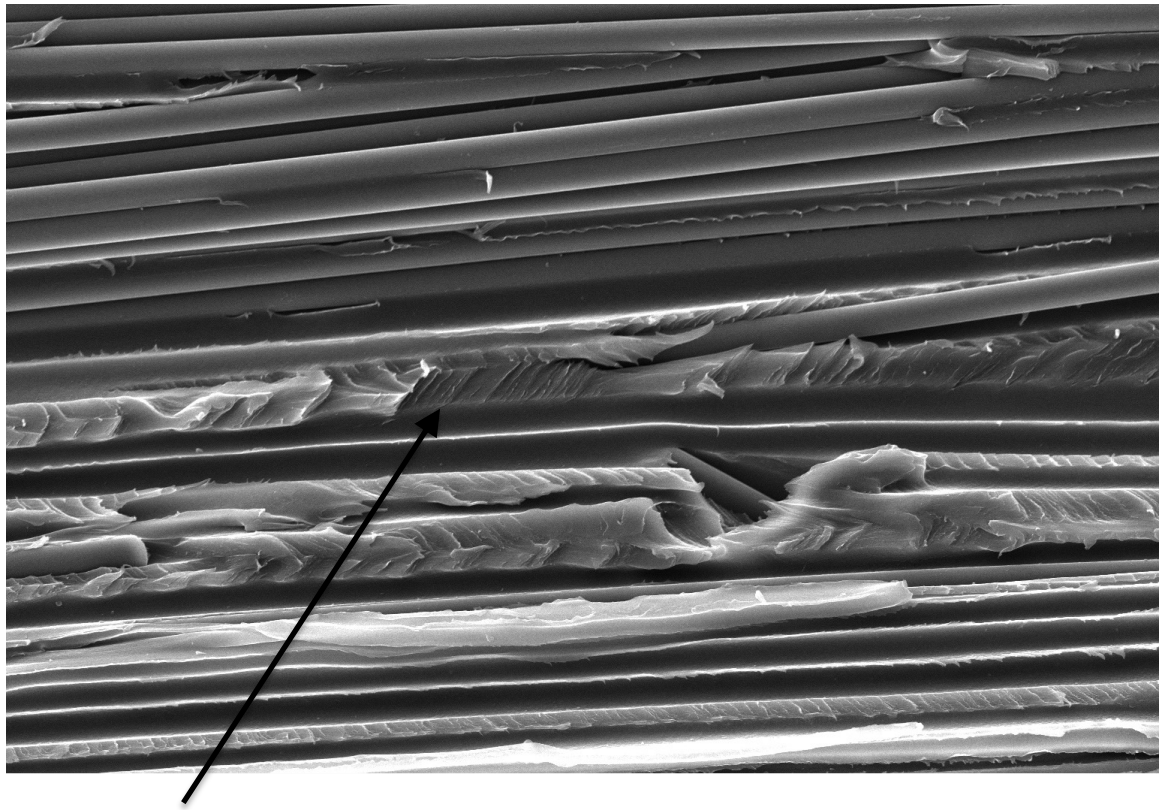
Brittle fracture

Ductile + Brittle fracture

Ductile fracture

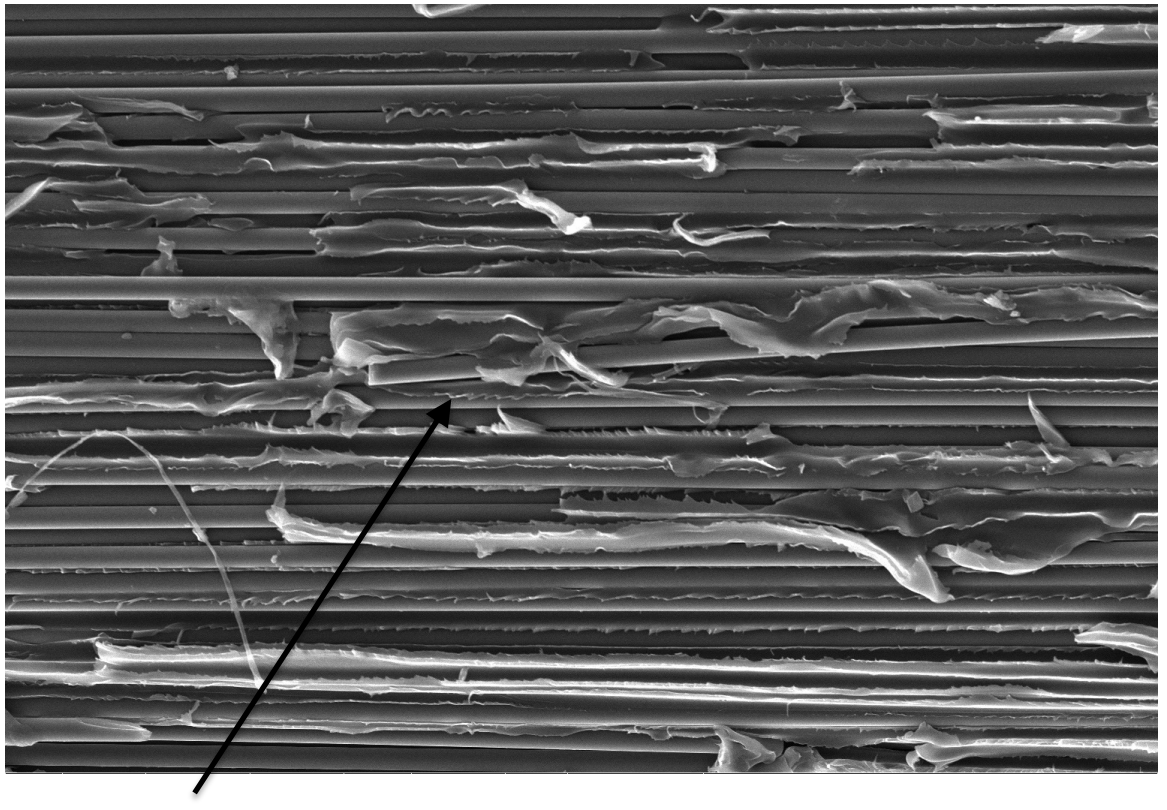
Fractography of Mode II Coupons

100 mm/s



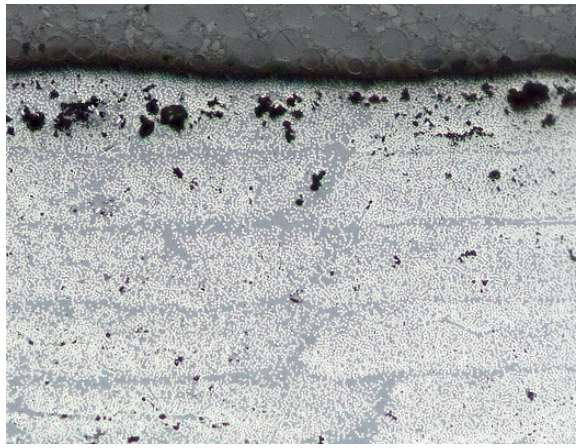
Brittle fracture (hackles)

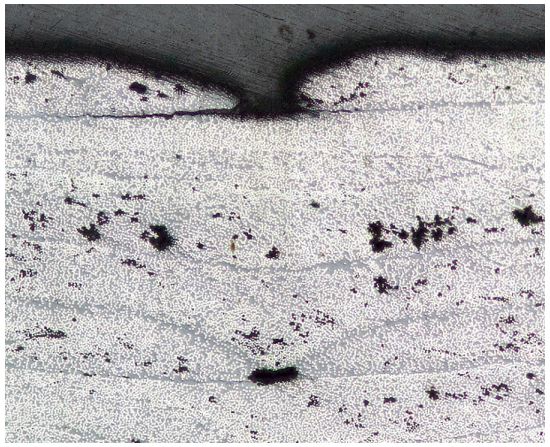
200 mm/s

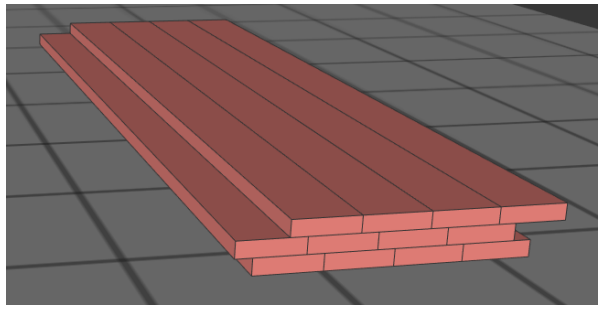


Ductile fracture (matrix tearing and stretching)

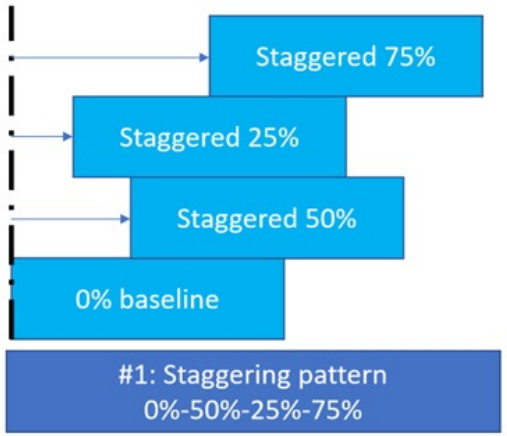
Effects of Gap Defects (Staggering)



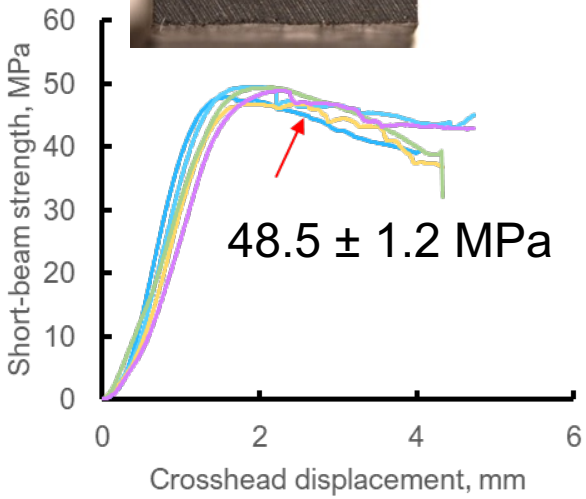


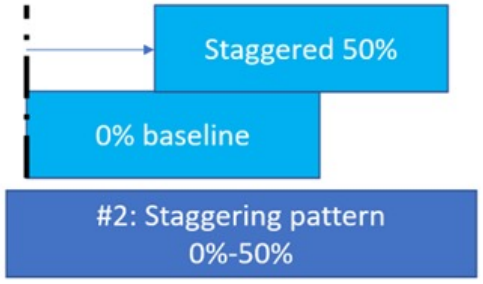


Staggering vs. SBS

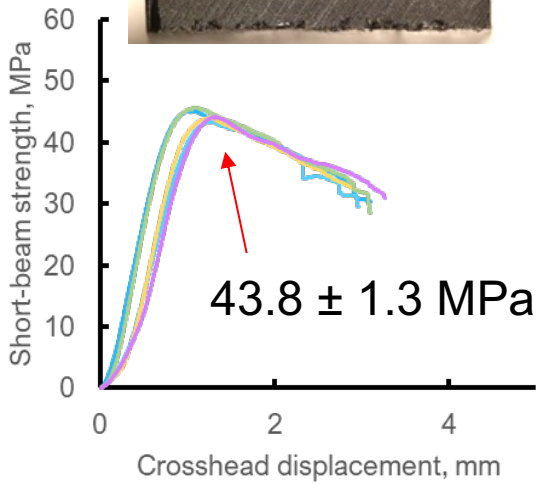


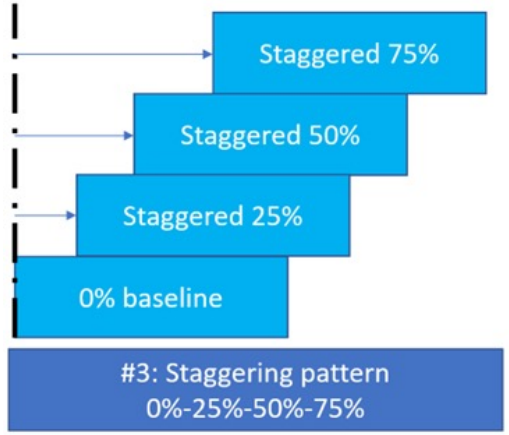
#1: Staggering pattern
0%-50%-25%-75%



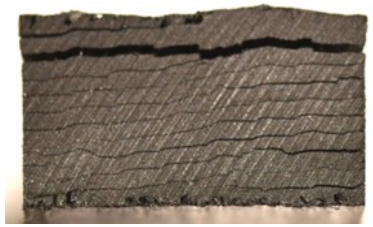


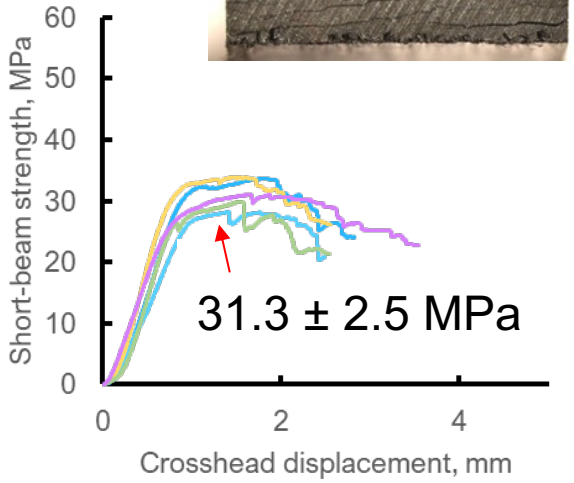
#2: Staggering pattern
0%-50%





#3: Staggering pattern
0%-25%-50%-75%





Conclusions

- ICAT is a complex process: bonding strength with intimate contact, interdiffusion and solidification interaction needs to be studied and better understood in the context of composite's multi-scale mechanics.

- High-rate AFP resulting in low SBS (<45MPa) and high porosities (>2%) may achieve damage resistance on par with thermosetting composites.

Acknowledgements

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