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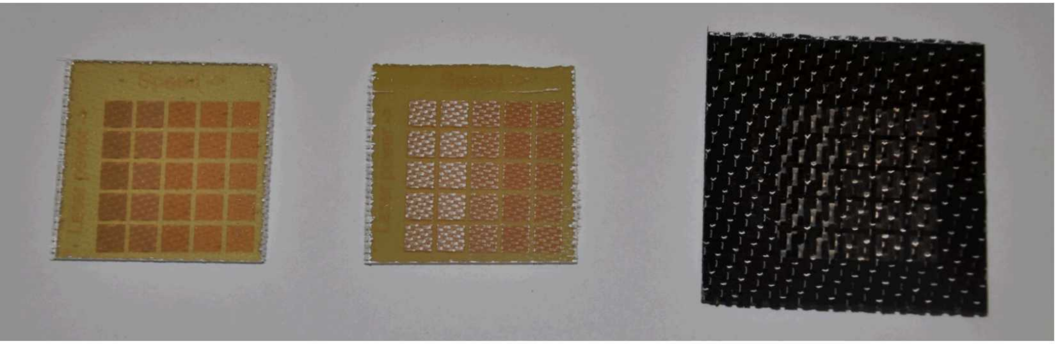

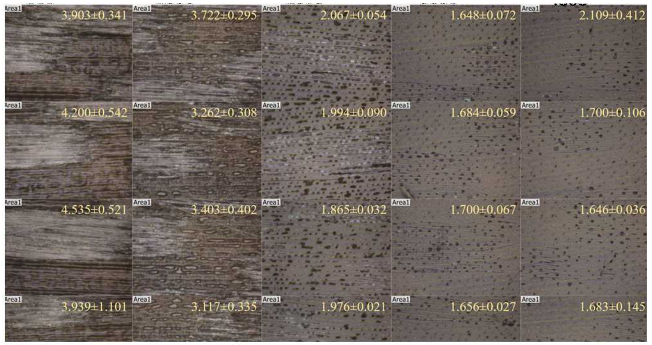

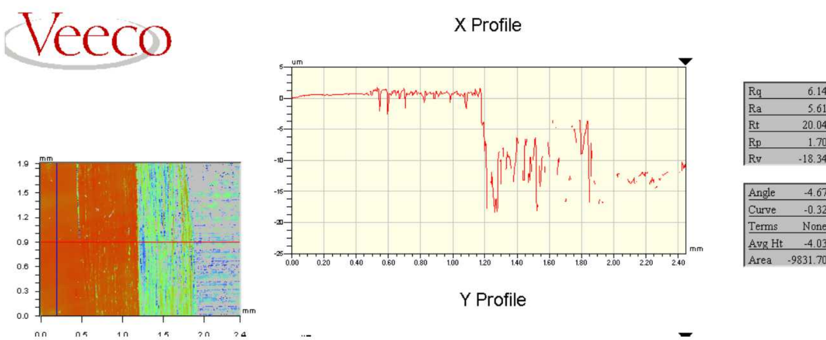

UV Laser Ablation of Composites: On the road towards improved adhesion through surface roughness analysis

Adriana Pavia Sanders (8344), Nalini Menon (8344), Jeffery Chames (8341-1), and Lee Massey (8344)

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Background
  - Ablation
  - Materials of interest
- Determining marking pattern
  - Crosshatch *vs* bidirectional
- Take a step back
  - Wider net needed to begin optimization
  - Surface roughness
    - Tool side *vs*. bag side
  - Cross-sectional data
  - Contact angle
- Ongoing/future work

Project goal

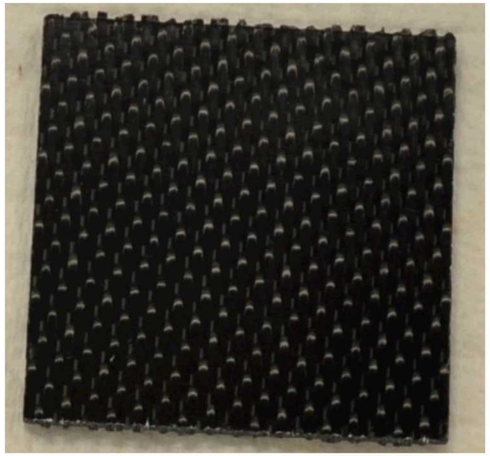
Develop an engineering process using UV laser ablation to remove surface contaminants from fiber reinforced composite surfaces to improve surface properties prior to bonding

Ultraviolet (UV) Ablation and Nomenclature

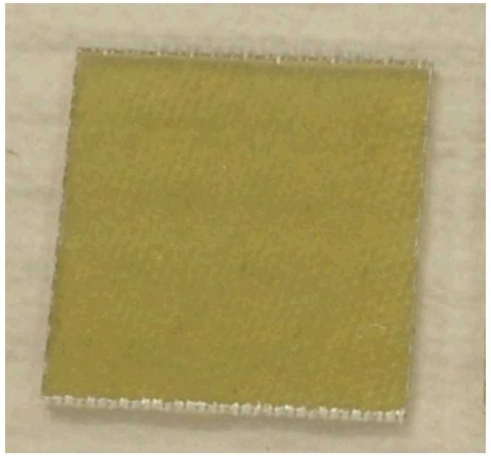
- Ablation
  - Removing material from a solid surface using laser irradiation through sublimation
  - Material dependent (due to
- Samurai UV laser ablation system
  - Compact Class IV laser with 3W average power at 355 nm wavelength
  - Spot size of 50 micron, energy output of 2.90 J/cm^2
  - Irradiance (power density) = >50 MW/cm^2
  - Maximum area = 17 cm X 17 cm
- Fluence
  - Irradiance × exposure time
- Ablation efficiency
  - Laser power × marking speed


Samurai UV Laser Ablation system in 941/1124-25

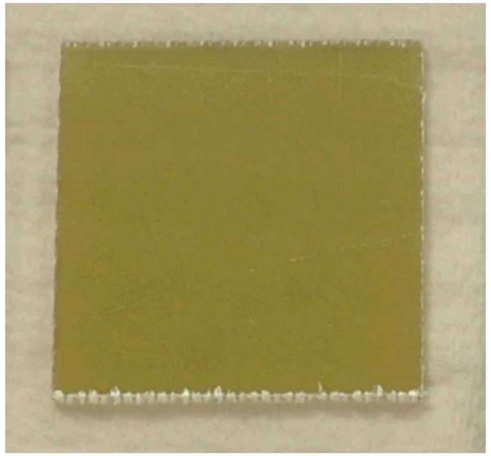
Materials of Interest



Carbon fiber composite (CFRP)

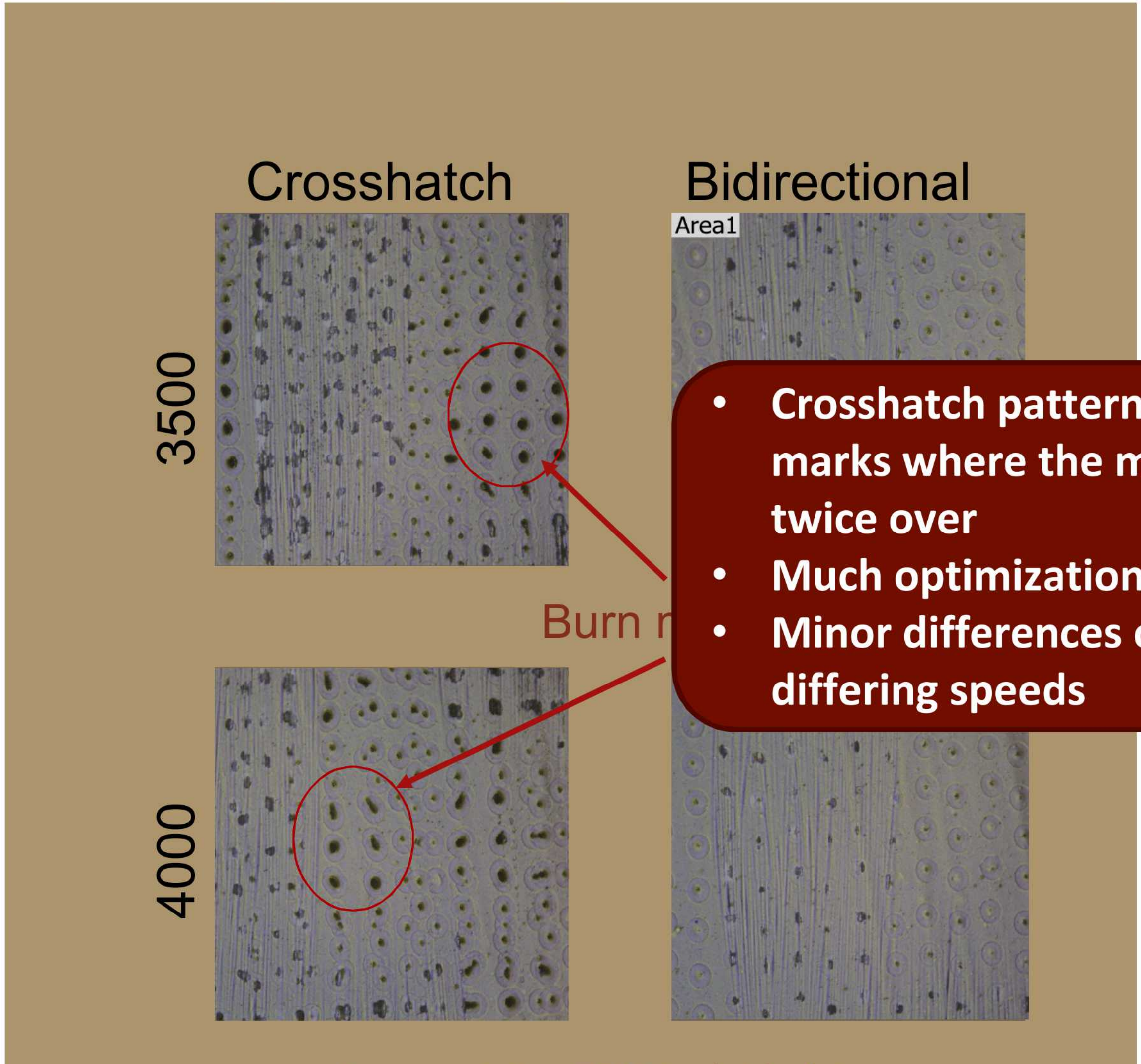


Glass fiber composite (GFRP)



GFRP with dry peel ply (GFRP-DPP)

Probing Marking Pattern



Representative GFRP tool side data

- **Crosshatch pattern results in burn marks where the material was ablated twice over**
- **Much optimization needed (slow down)**
- **Minor differences observed with differing speeds**

Keyence VK-X 3D laser microscope data

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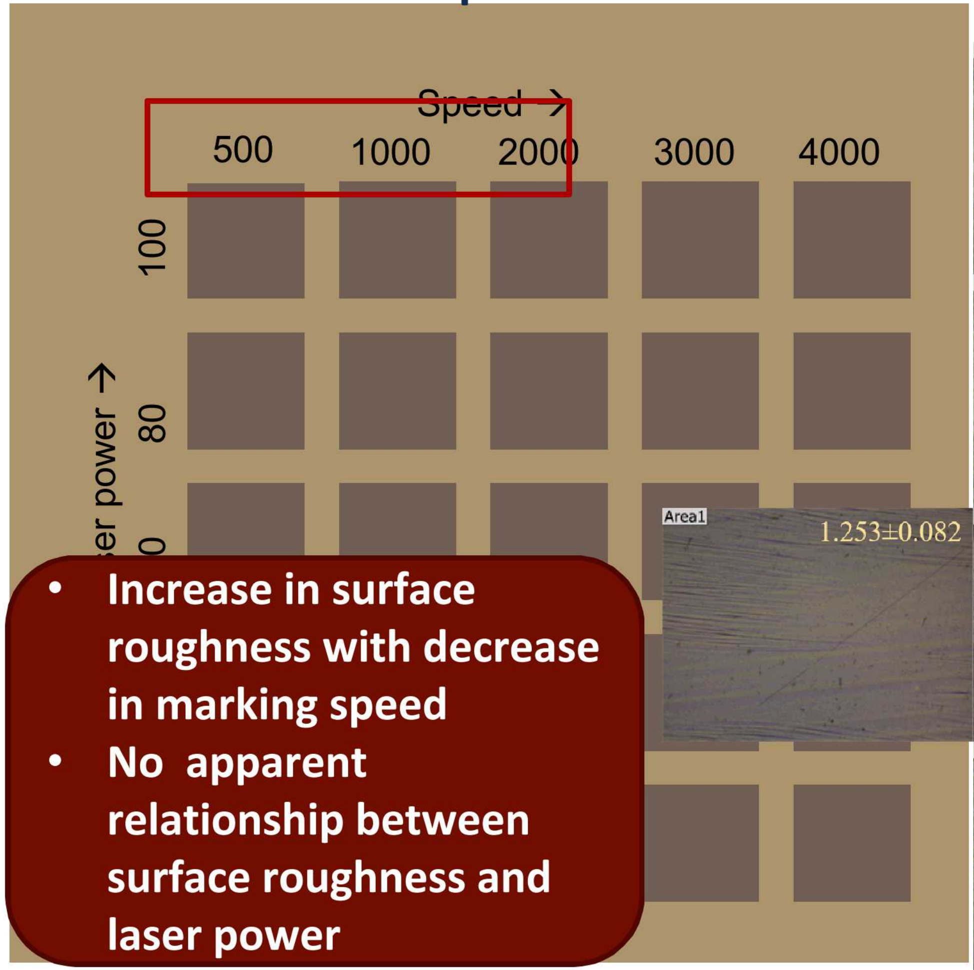
Composite Surface	Marking speed	Pattern	Surface roughness
CFRP (Tool side) (0.920)	3500	Bi-Di	2.031 ± 0.090
		Cross Hatch	2.112 ± 0.168
	4000	Bi-Di	1.880 ± 0.079
		Cross Hatch	1.984 ± 0.078
[illegible]	3500	Bi-Di	1.257 ± 0.032
		Cross Hatch	1.720 ± 0.049
	[illegible]	Bi-Di	1.273 ± 0.028
		Cross Hatch	1.640 ± 0.035
[illegible]	[illegible]	Bi-Di	9.981 ± 2.64
		Cross Hatch	9.843 ± 0.562
	4000	Bi-Di	11.358 ± 1.29
		Cross Hatch	9.056 ± 1.40
GFRP (Bagged side) (2.464)	3500	Bi-Di	3.793 ± 0.121
		Cross Hatch	4.749 ± 0.128
	4000	Bi-Di	3.724 ± 0.667
		Cross Hatch	3.381 ± 0.584

2×2 ablation performed by Lee Massey

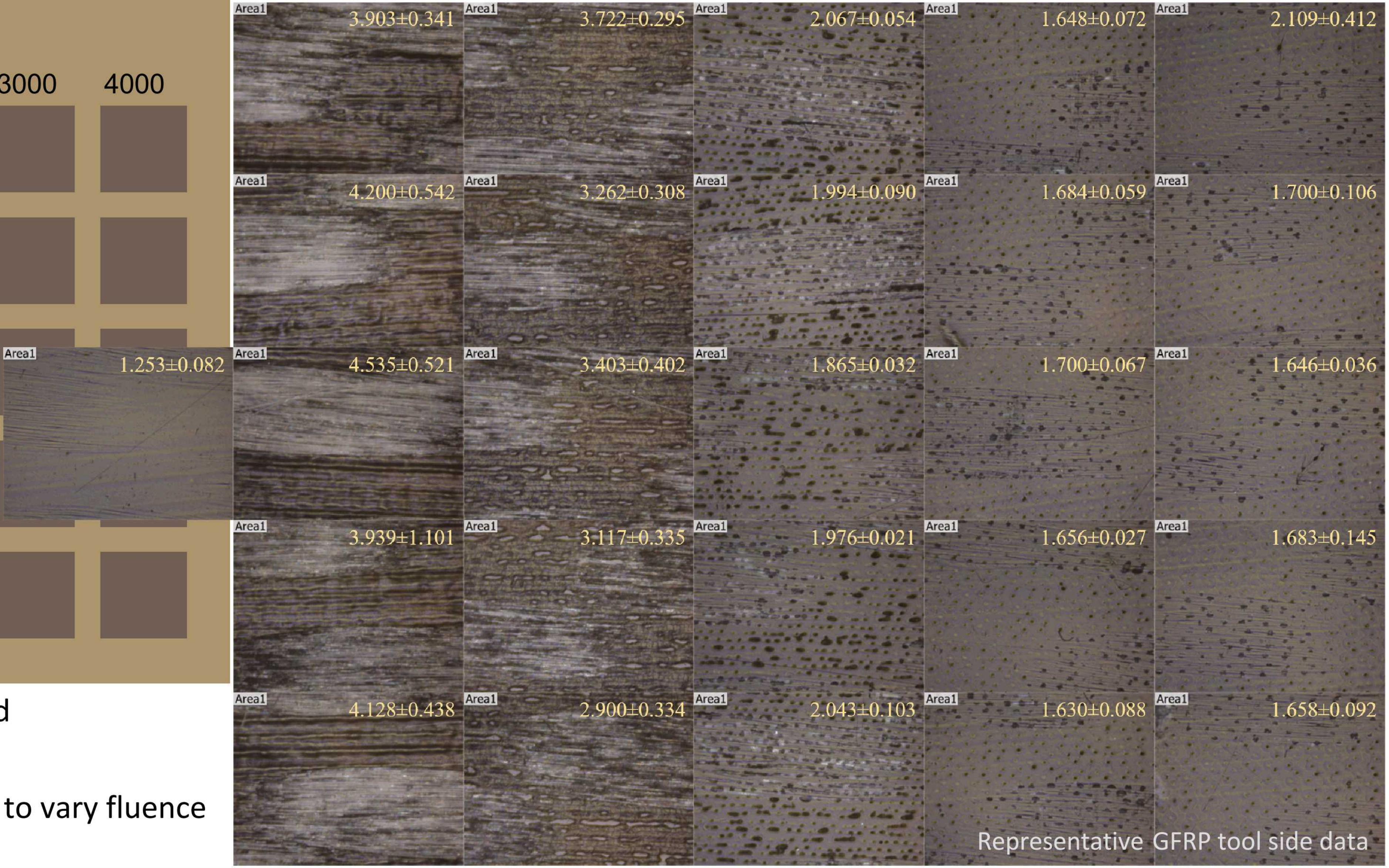
Surface roughness in µm

Take a Step Back



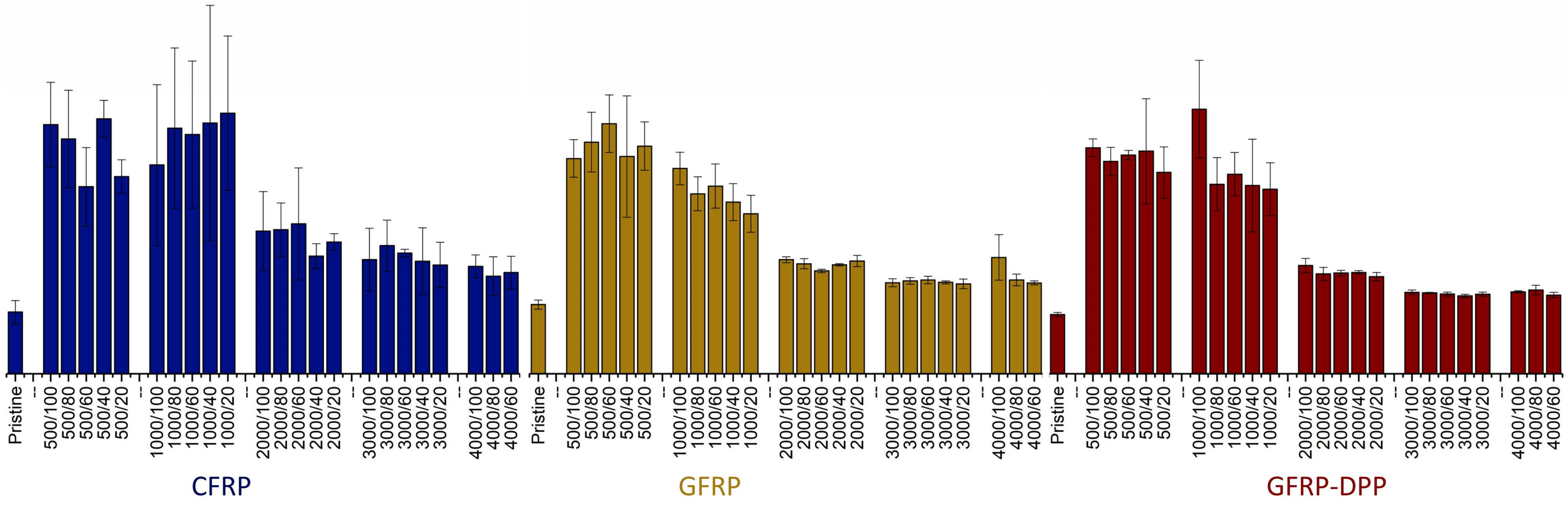
- Increase in surface roughness with decrease in marking speed
- No apparent relationship between surface roughness and laser power

Decrease in surface roughness



- Need to optimize marking speed
  - 500 – 4000 mm/s
- Varying laser power as a means to vary fluence
  - 20% – 100%

Effect of Laser Power



- Difference in roughness within the noise
- Greater variation at slower speeds may be due to exposed fiber bundles

Surface Roughness Data for Tool and Bag Side

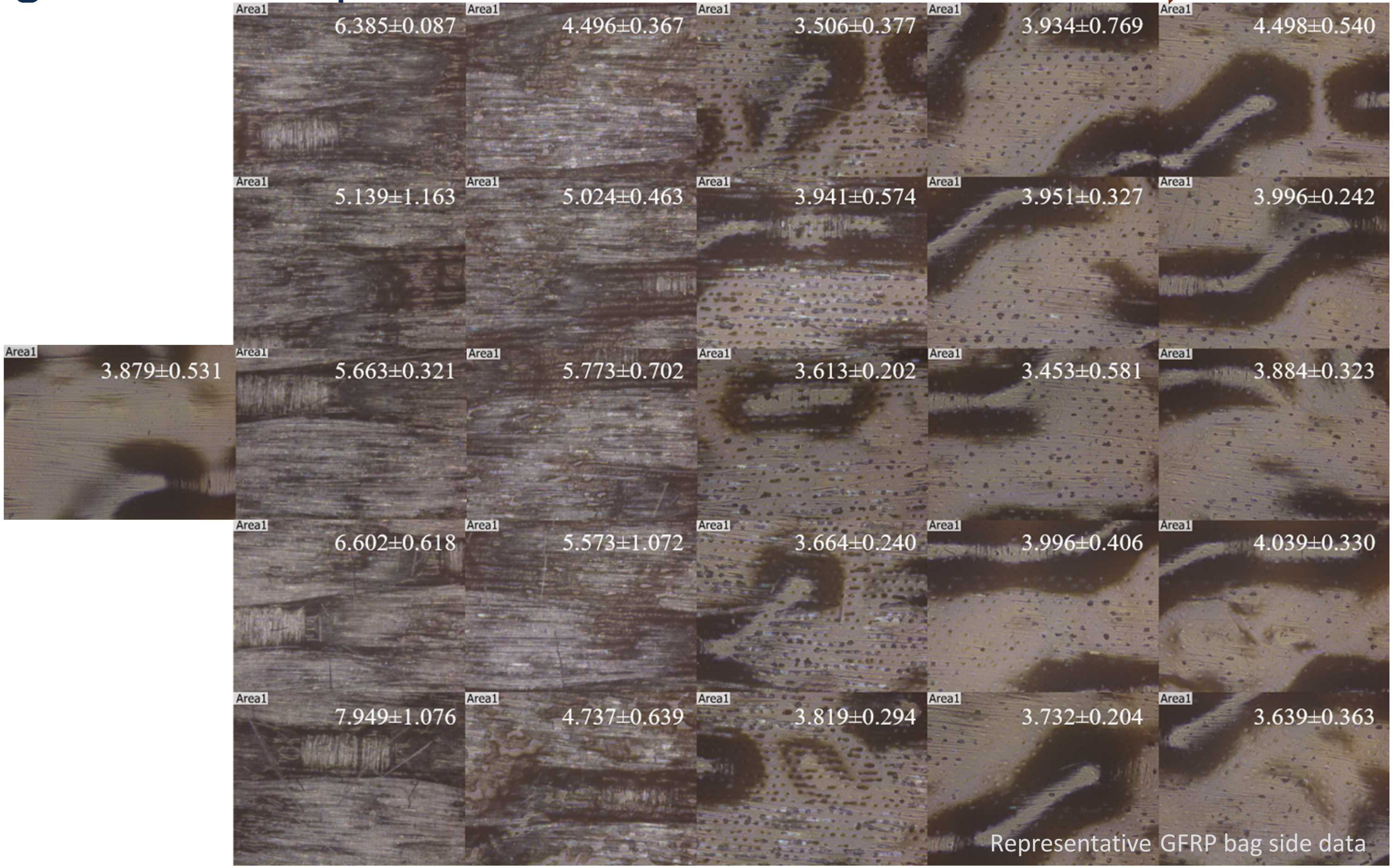
- Representative data at 100% laser power
- Tool side

Material	Pristine	500 mm/s	1000 mm/s	2000 mm/s	3000 mm/s	4000 mm/s
GFRP	1.253±0.082	3.903±0.341	3.722±0.295	2.067±0.054	1.648±0.072	2.109±0.412
GFRP-DPP	1.071±0.040	4.097±0.159	4.796±0.887	1.963±0.126	1.477±0.041	1.485±0.019
CFRP	1.117±0.211	4.518±0.767	3.786±1.457	2.587±0.715	2.068±0569	1.948±0.204

- **Surface roughness increases with decrease in marking speed**
- **All ablation results in increase of surface roughness (from pristine)**

Bag Side of Composite

General decrease in surface roughness →



Representative GFRP bag side data

Surface Roughness Data for Tool and Bag Side

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- **Surface roughness increases with decrease in marking speed**
- **All ablation results in increase of surface roughness (from pristine)**

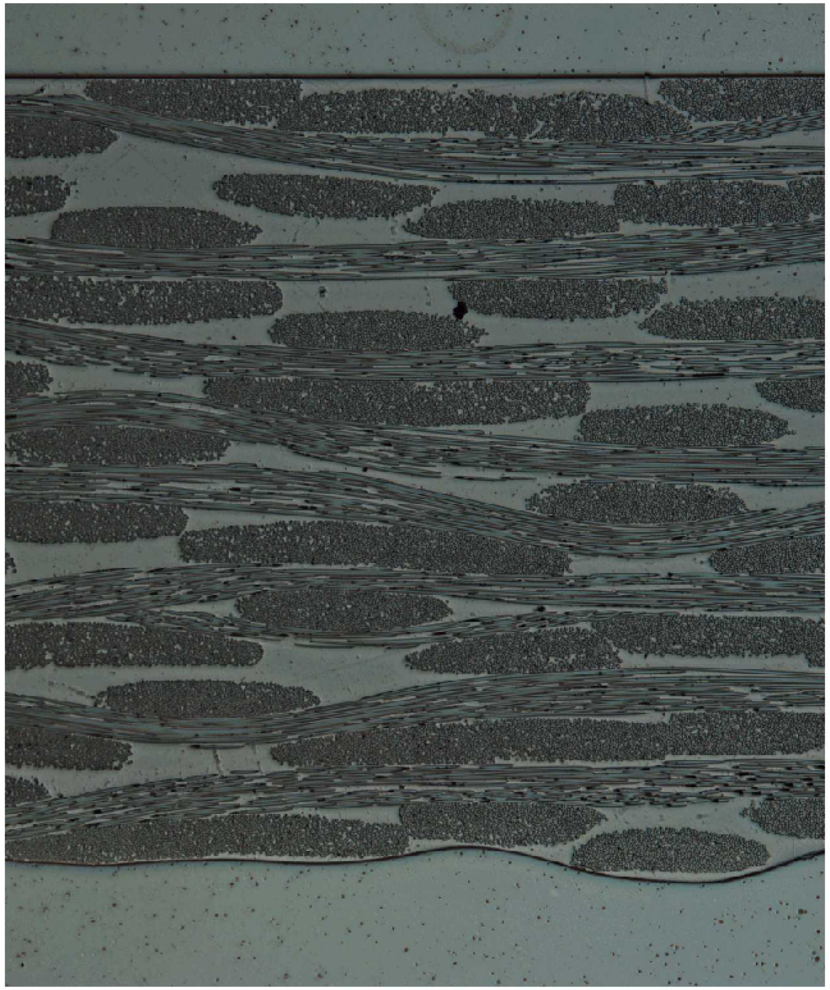
- Bag side

Material	Pristine	500 mm/s	1000 mm/s	2000 mm/s	3000 mm/s	4000 mm/s
GFRP	3.879±0.531	6.385±0.087	4.496±0.367	3.506±0.377	3.934±0.769	4.498±0.540
GFRP-DPP	8.060±3.050	7.125±0.214	7.876±0.409	9.034±2.665	9.710±3.761	8.910±2.264
CFRP	2.987±0.952	5.882±0.221	4.985±0.176	5.534±0.706	5.979±1.217	7.191±0.218

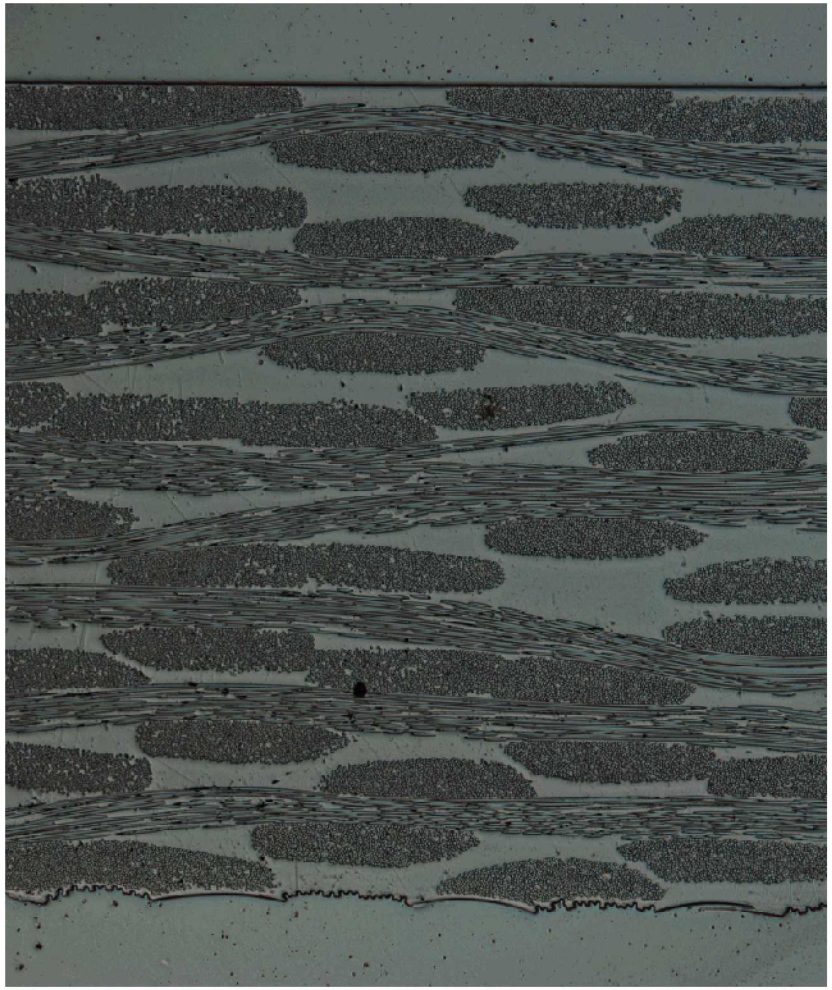
- **Trend harder to observe**
- **Some ablated area results lower than pristine material**
- **Difference due to inherent "rougher" starting point**

Bag *vs*. Tool Side Unablated Materials

CFRP

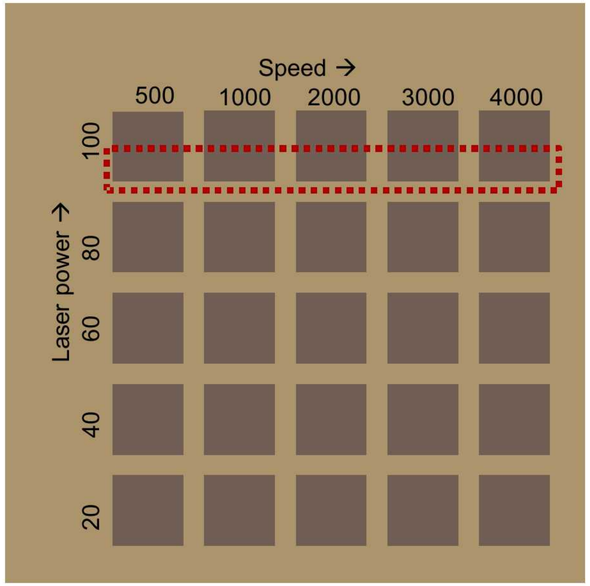


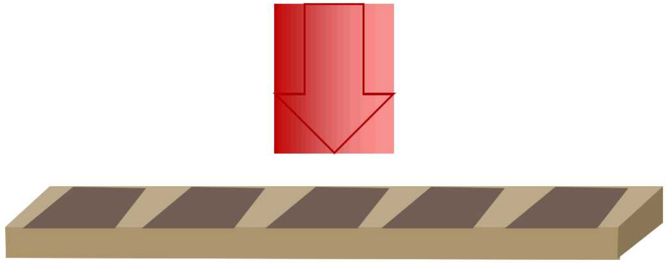
GFRP



GFRP-DPP

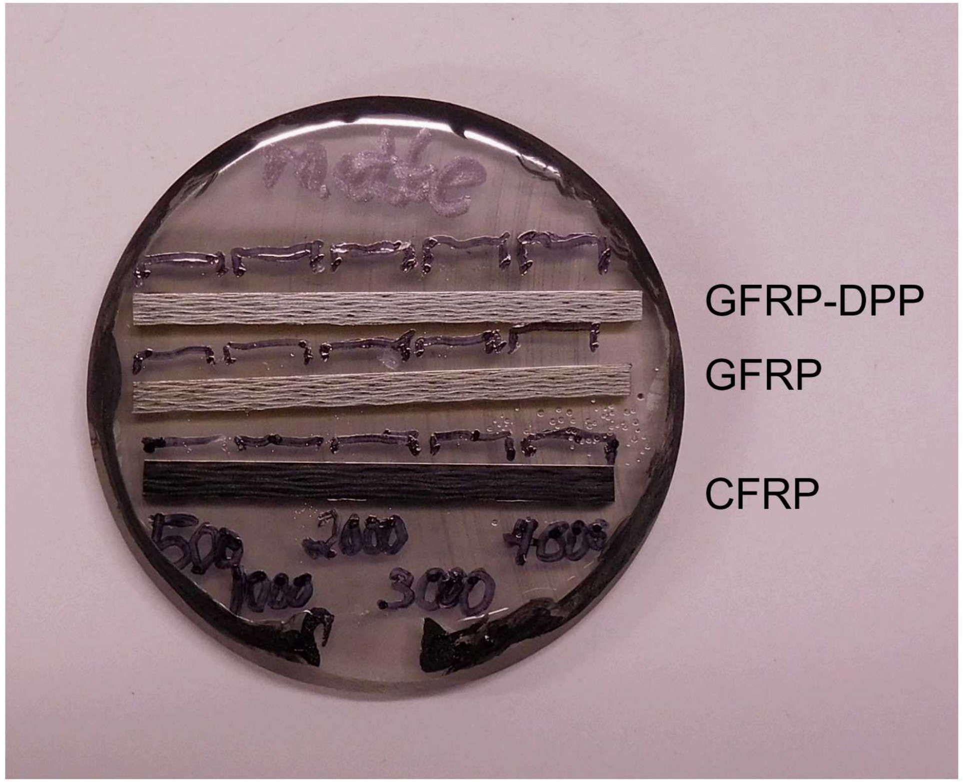
Cross-sectional Microscopy





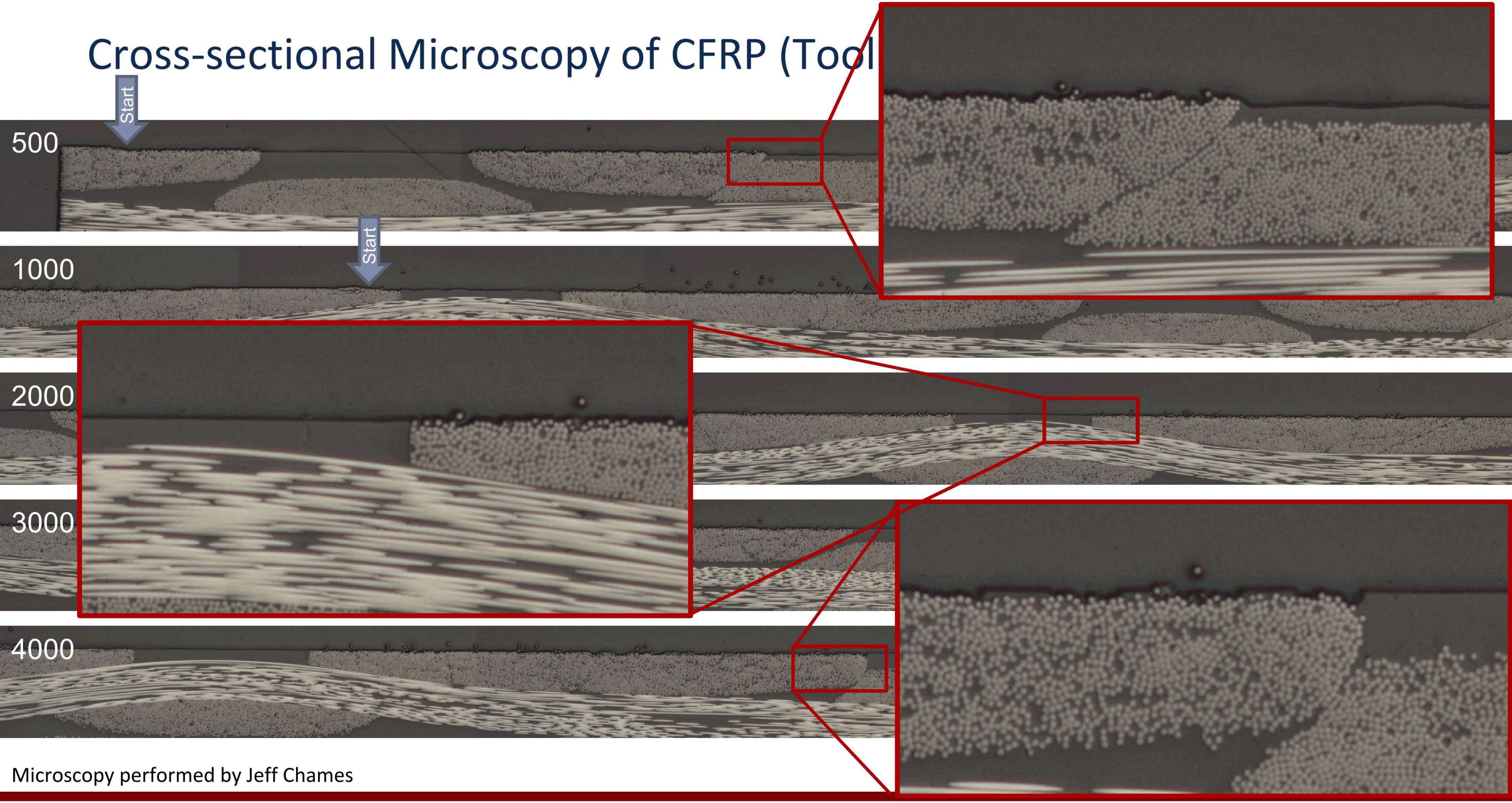
- Top row cut out and potted for cross-sectional analysis
- Performed on unablated and ablated materials

Remainder of presentation will focus on tool side of materials



Microscopy performed by Jeff Chames

Cross-sectional Microscopy of CFRP (Tool



Microscopy performed by Jeff Chames

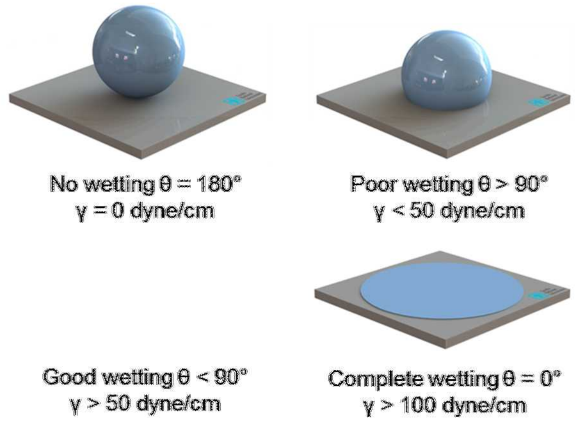
Contact Angle

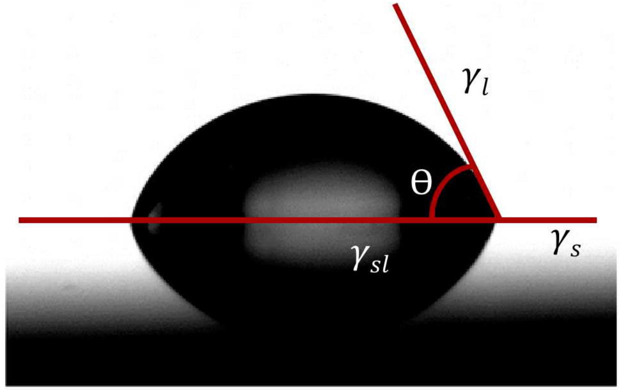
- Contact angle through sessile drop
- Young's equation

$$\gamma_s = \gamma_{sl} + \gamma_l cos\theta$$

- As it relates to work of adhesion

$$W_A = \gamma_l(1 + cos\theta)$$





Surface	Surface treatment	Contact angles (degrees)	Work of Adhesion (Joules)
GFRP-DPP bag	Non-ablated	82.3	81.91
	Ablated	80.6	83.97
GFRP-DPP tool	Non-ablated	88.7	78.35
	Ablated	78.9	81.54
GFRP bag	Non-ablated	95.4	68.89
	Ablated	86.1	75.73
GFRP tool	Non-ablated	74.6	90.12
	Ablated	69.9	96.33

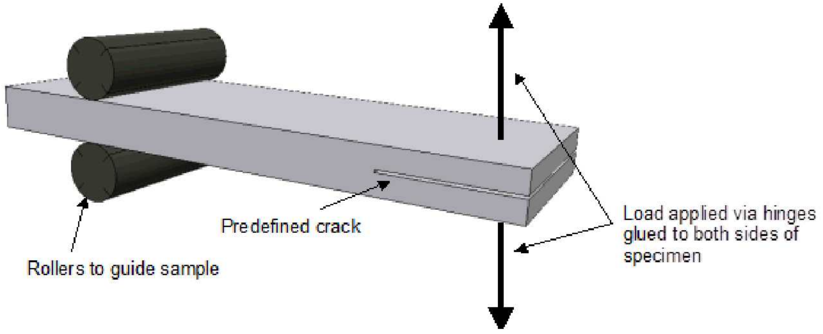
Representative data for GFRP and GFRP-DPP

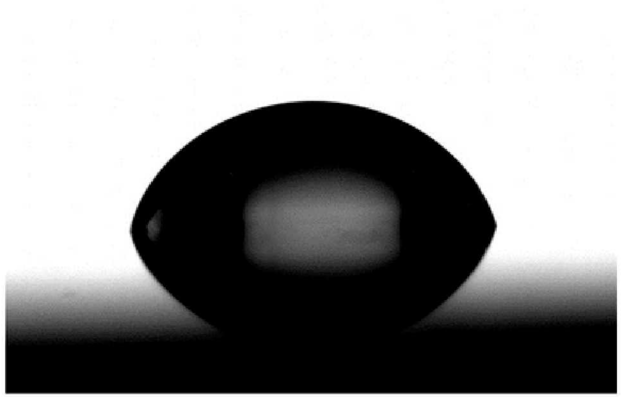
Collection of contact data is ongoing

Contact data collected by Nalini Menon

Ongoing and Future Work

- Continue collecting contact angle data
  - Work of adhesion
  - Surface energy
- Relate surface roughness with adhesive behavior
  - Double cantilever beam (DCB) testing
- Fine tune ablation requirements





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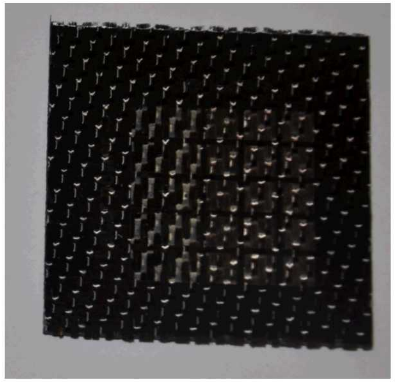

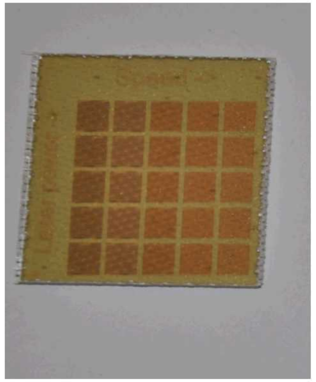

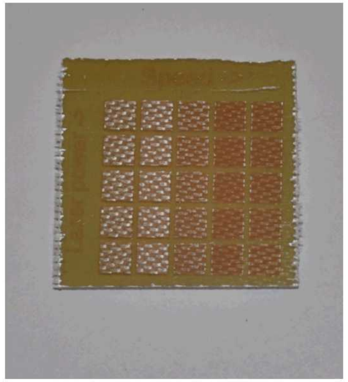

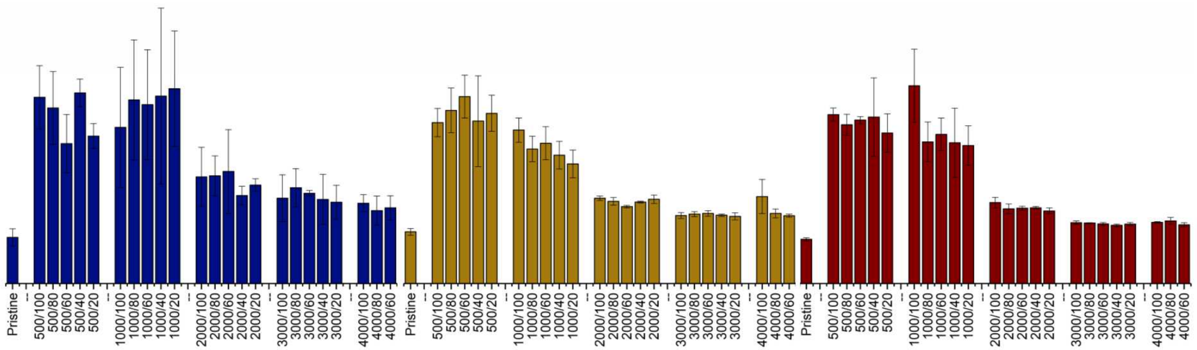

Questions?