Characterizing the Unique Properties of Natural-Fiber Composites Nondestructively

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NASA Langley Research Center

Nondestructive Evaluations Science Branch

2024 Summer Final Presentation

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Project SUMAC (SUstainable Manufacturing in AirCraft)

➢ Objective: Reduce environmental impact of commercial air transport by developing sustainable composites using natural and bio-friendly materials for aircraft.

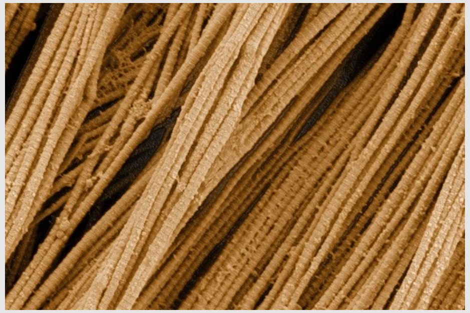
Why Natural Fiber Composites?

- Smaller Carbon Footprint
- Biodegradable
- Potentially Damage Tolerant
- Improved Sustainability

Challenges

- Lower Strength
- Moisture Absorption
- Changing Elastic Properties
- Long term durability

Flax (Natural Fiber)



Hemp (Natural Fiber)

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Integrated Sensing Approach

Nondestructive Evaluation (Active)

- Step 1: Input energy into material nondestructive
- Step 2: Analyze the interaction
- Step 3: Determine something about the material

Material Characterization

Physical Properties	Mechanical Properties	Electrical Properties

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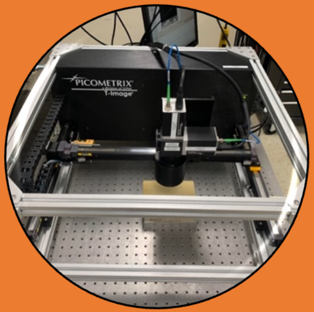
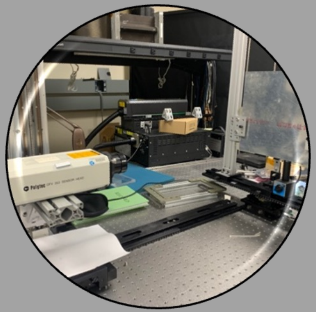
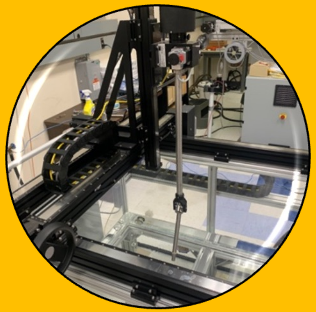
NDE Techniques Utilized



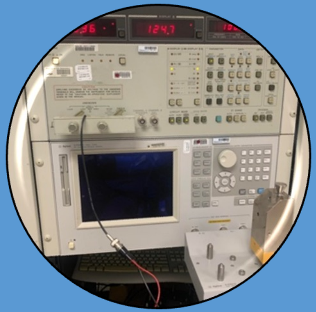
Terahertz Time-Domain Spectroscopy



Laser Doppler Vibrometry



Ultrasonic Polar backscatter



Inductance, Capacitance, and Impedance Analysis

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Terahertz Time-Domain Spectroscopy

Flax Natural Fiber Composite

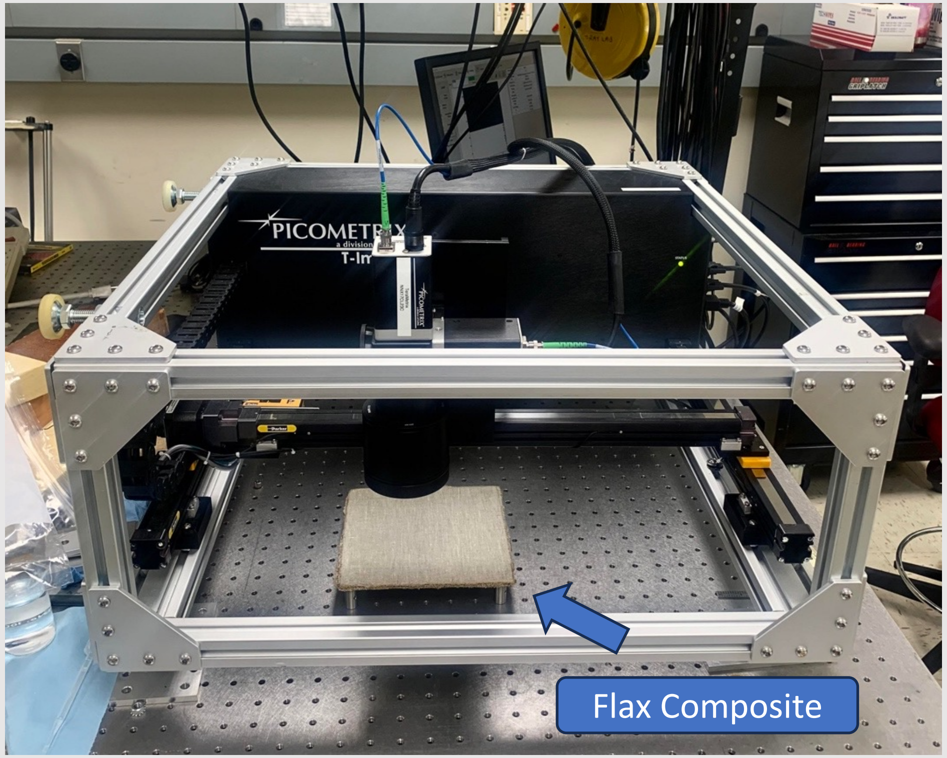
- 14 Layers
- Polyvinyl Alcohol Resin
- Two fiber layups:
  - Bouligand Fiber Structure (Spiral Directional)
  - Quasi-Isotropic Fiber Structure e.g.
  - (-45°, 0°, 45°, 90°)
- Polyvinyl Alcohol Resin
- Full Panel: 7in x 7 in

Terahertz System Optimization

- How long do these scans take?
- Optimum scanning speed without losing data quality?
- Optimum scanning distance from lens?

Detection Abilities

- Fiber Direction?
- Moisture Uptake?
- Discontinuities?
- Imperfections?



Terahertz Scanning System

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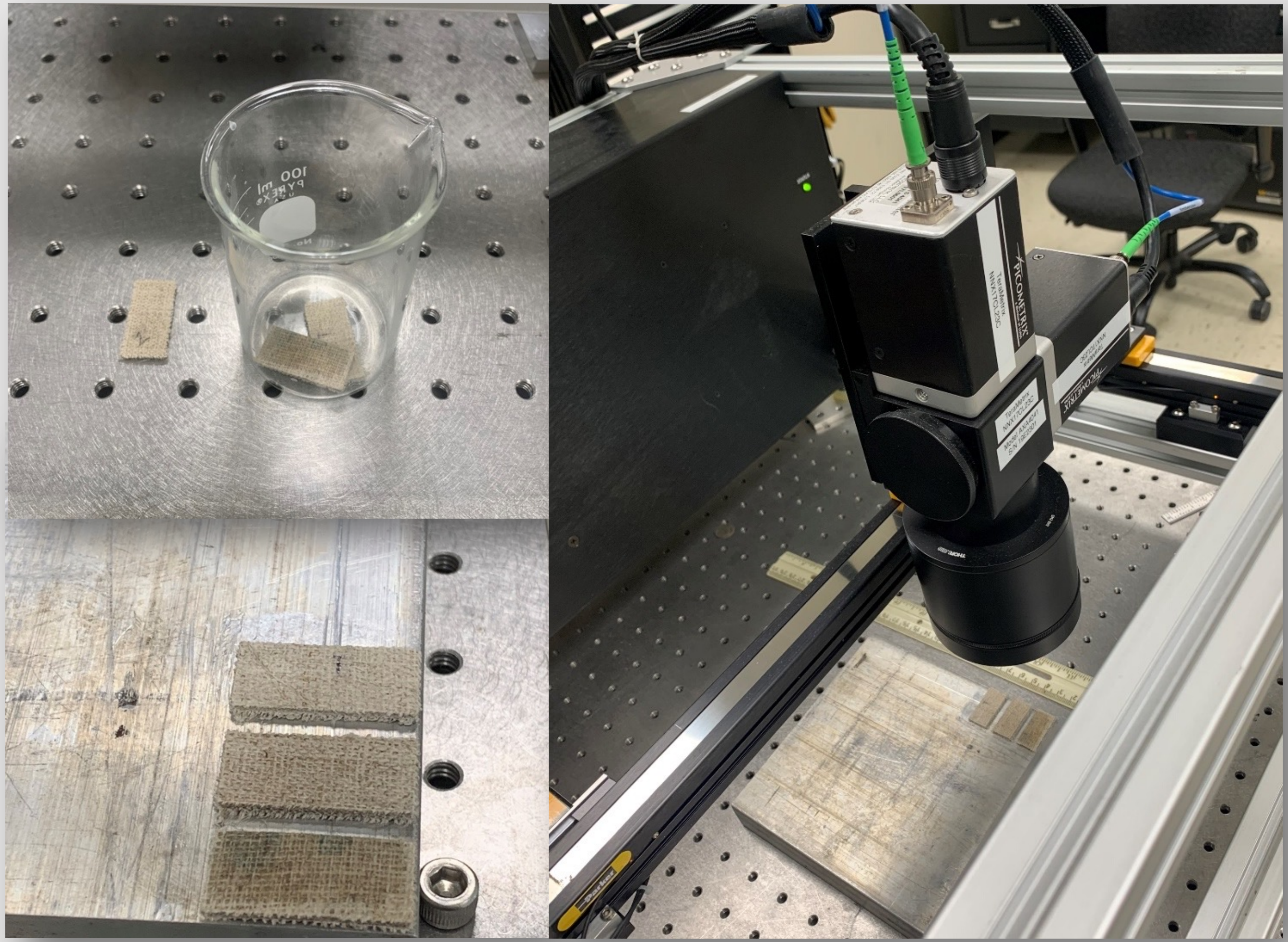
Objective: Determine if THz Time Domain Spectroscopy can Detect moisture content in natural fiber composites

Moisture Experiment

Parameters	10mm x 27.5mm Bouligand Flax Samples
	S1: Dry (Atmospheric Moisture)
	S2: 15 Minutes (Soaked)
	S3: 30 Minutes (Soaked)
	Scanned Area: 30mm x 50mm
	Area per Pixel 0.2mm^2



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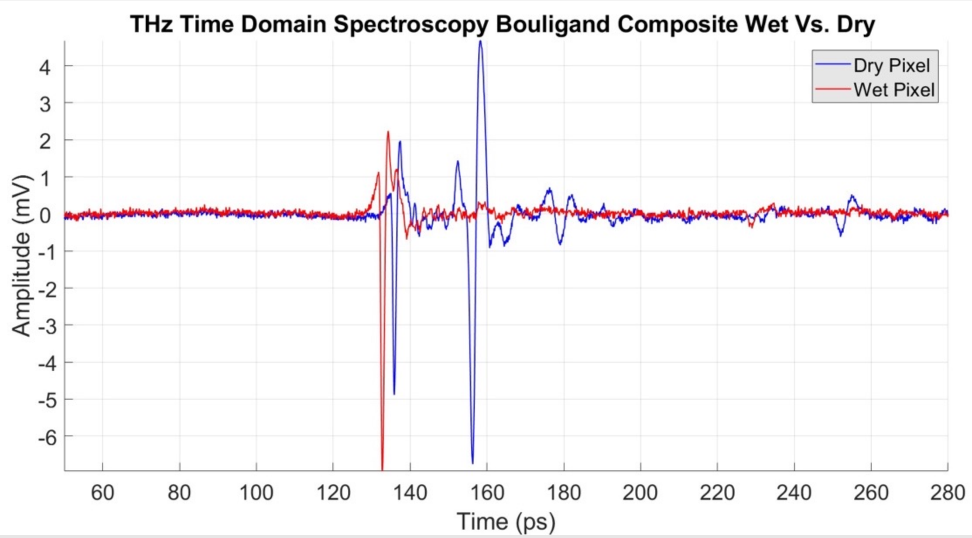
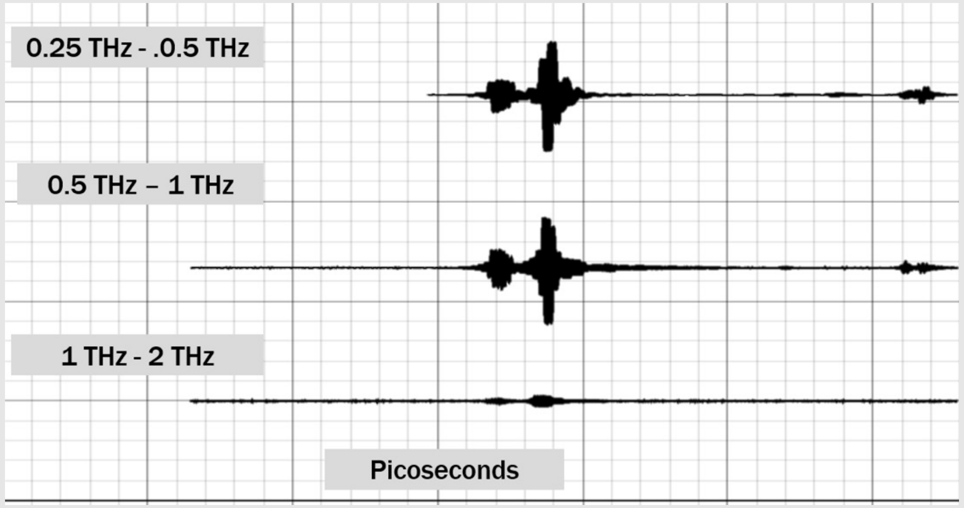
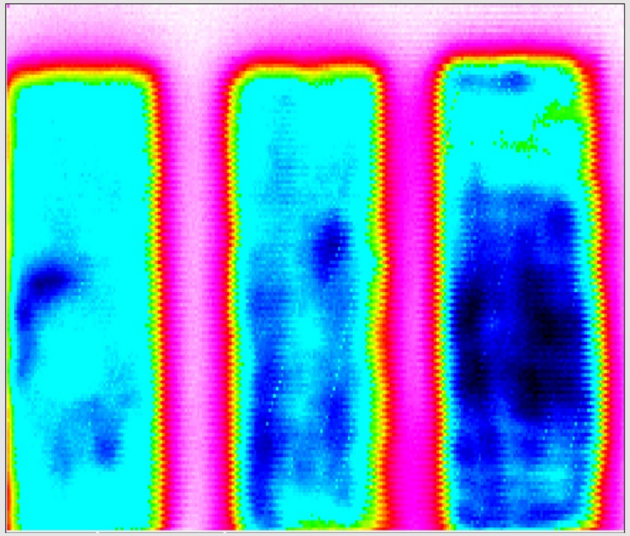


Band Pass of all Waveforms Compiled



THz attenuation in flax composites at various water soaking times
Full THz Band (130ps – 140ps)



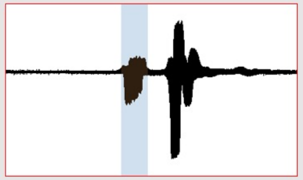
Dry 15 Min 30 Min

6.5mV – 8.5mV

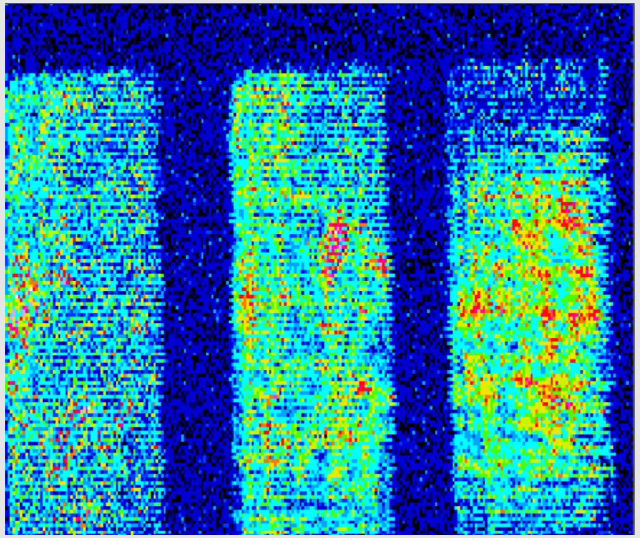
3.5mV – 5.5mV

0.5mV – 2.5mV

Full THz Band



THz attenuation in flax composites at various water soaking times
1 THz – 2 THz (130ps – 140ps)

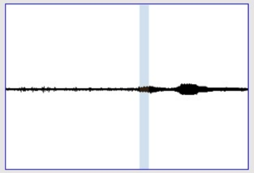


6.5mV – 8.5mV

3.5mV – 5.5mV

0.5mV – 2.5mV

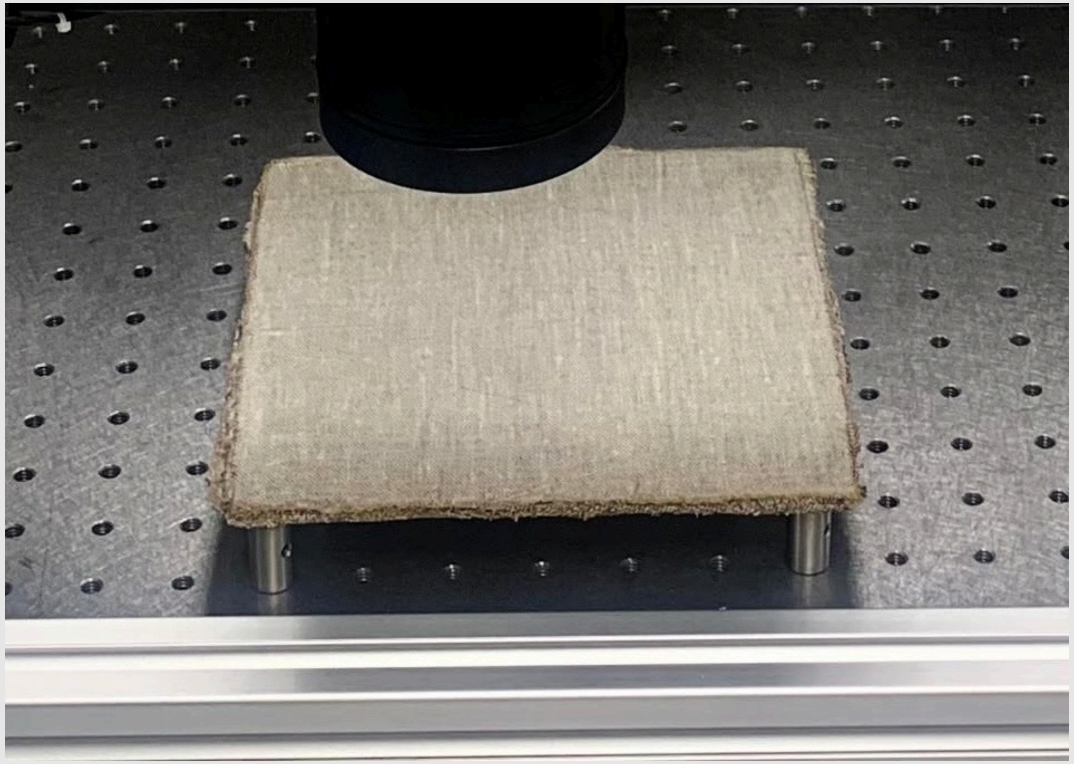
1 THz – 2 THz



Distance Offset Experiment

Objective: Find the optimum distance of maximum THz intensity, and the best signal to noise ratio

Parameters	
	Bouligand Flax Panel
	No Backplate
	Distances from the Optic measured (inches):
	4.248, 4.748, 5.248, 5.375, 6.248



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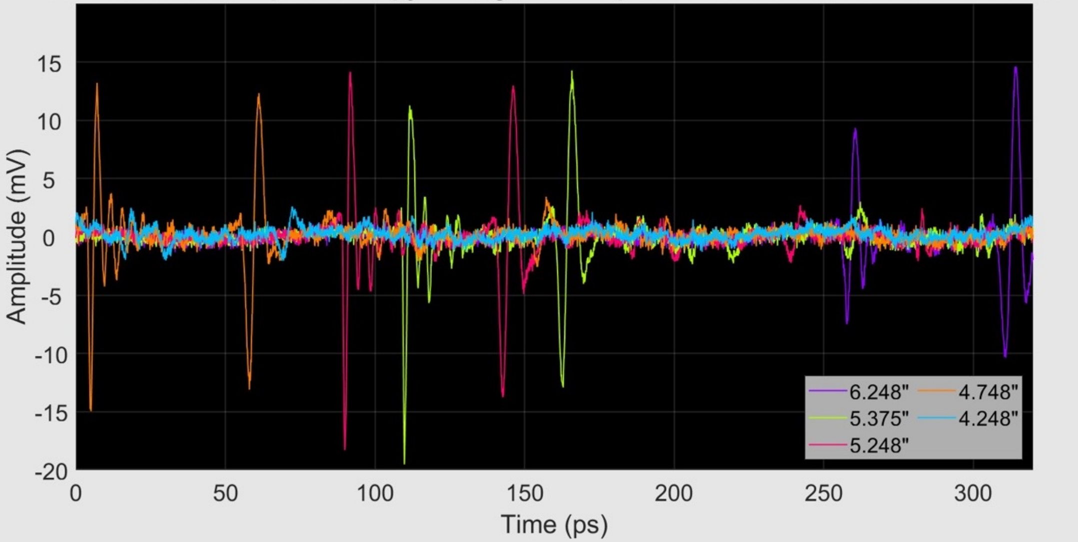
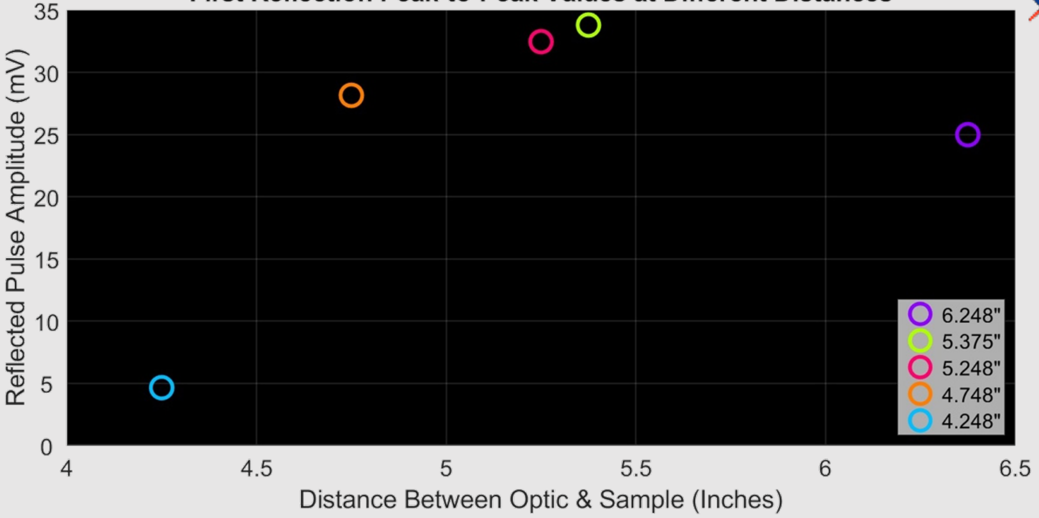
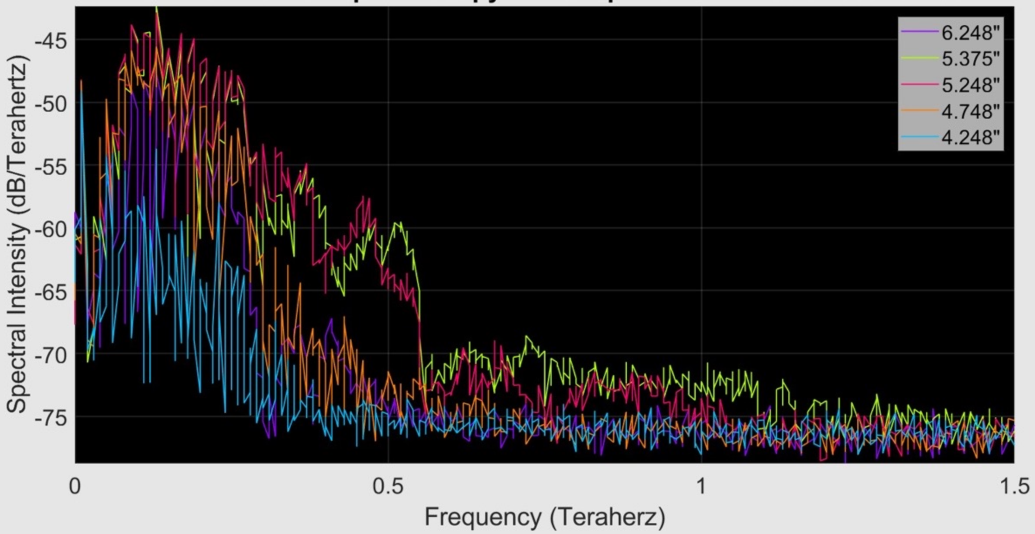
THz Time Domain Spectroscopy Bouligand Composite Reflection at Different Distance



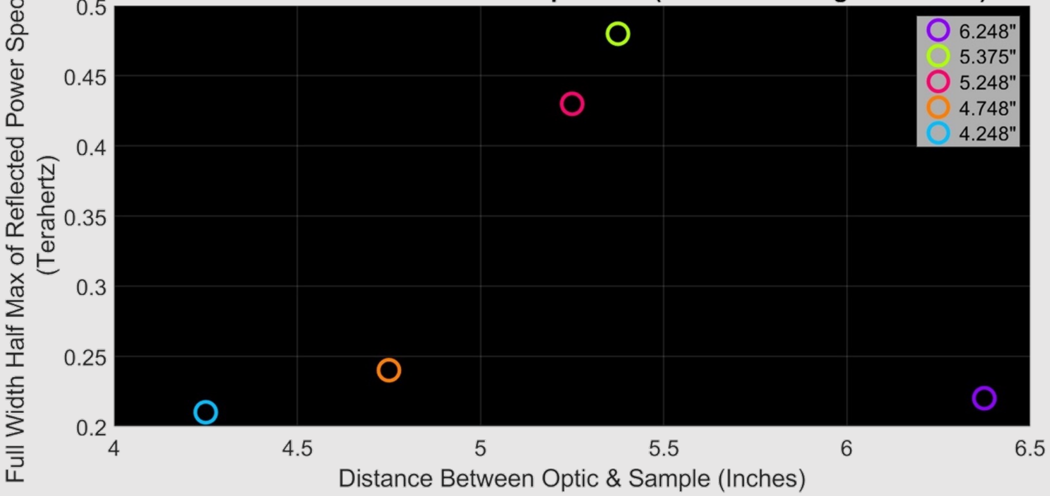
THz Time Domain Spectroscopy Bouligand Composite
First Reflection Peak-to-Peak Values at Different Distances



THz Time Domain Spectroscopy Power Spectrum at Different Distances



THz Time Domain Spectroscopy Bouligand Composite
Full Width Half Max of Reflected Spectrum (With Smoothing Estimation)



THz Time Domain Spectroscopy Observations

THz Time Domain Spectroscopy

- Detects moisture content
- Easily penetrates Flax composites

Optimum Scanning Height

- 5.25in – 5.375 in From Lens

Optimum Scanning Speed

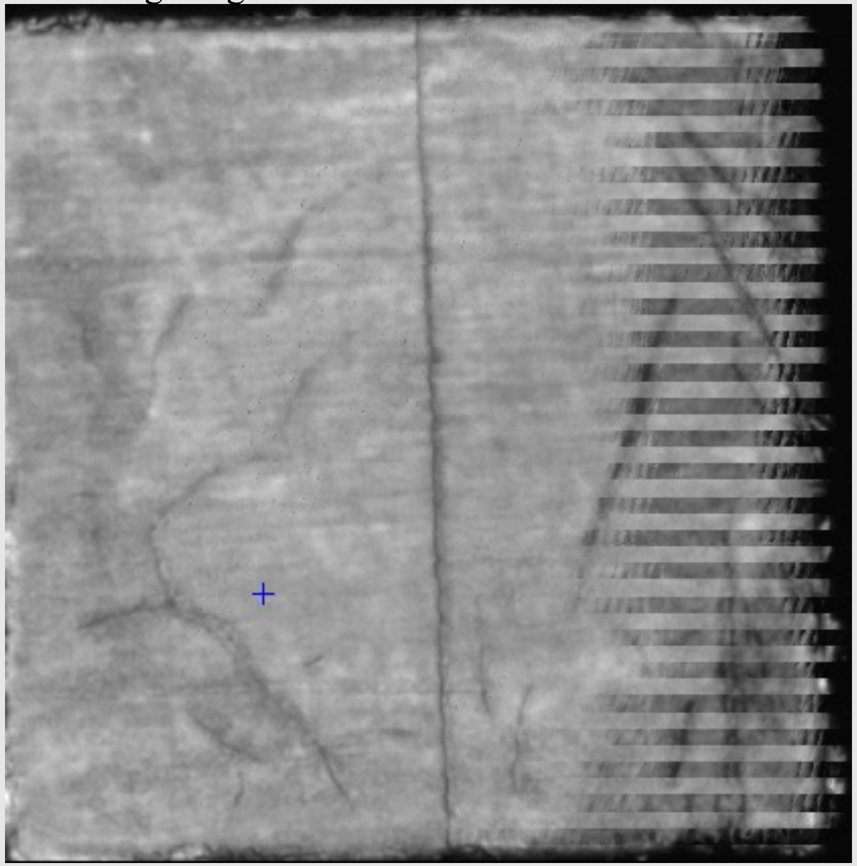
- Depends on the level of resolution desired

Highest Intensity Bandwidth

- 0.1 THz – 0.6 THz

Full Field Bouligand Flax Scan

Scanning Speed: 1mm/sec
Pixel Size: 0.2mm
Waveforms per pixel: 20
Scanning Time: 2 days
Scanning Height from lens: 5.248 inches



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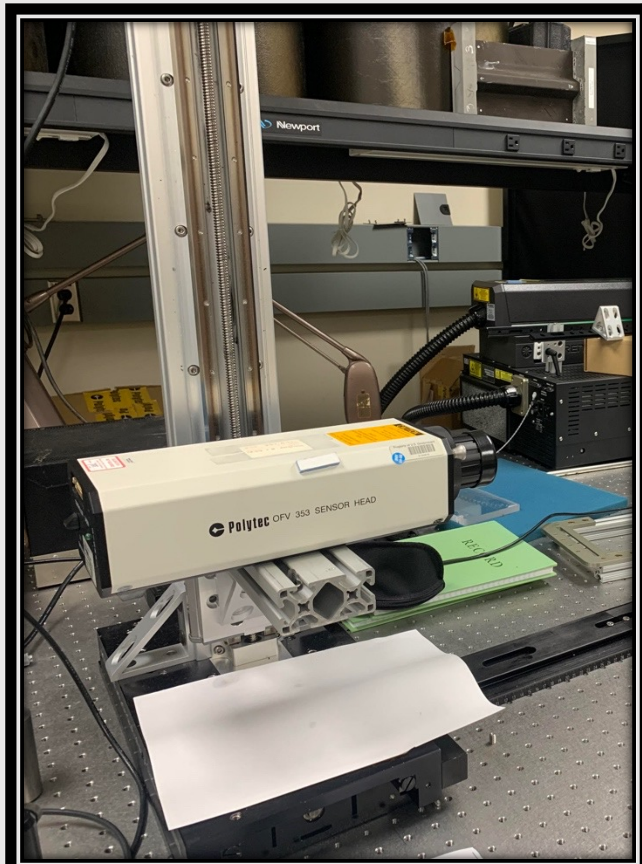
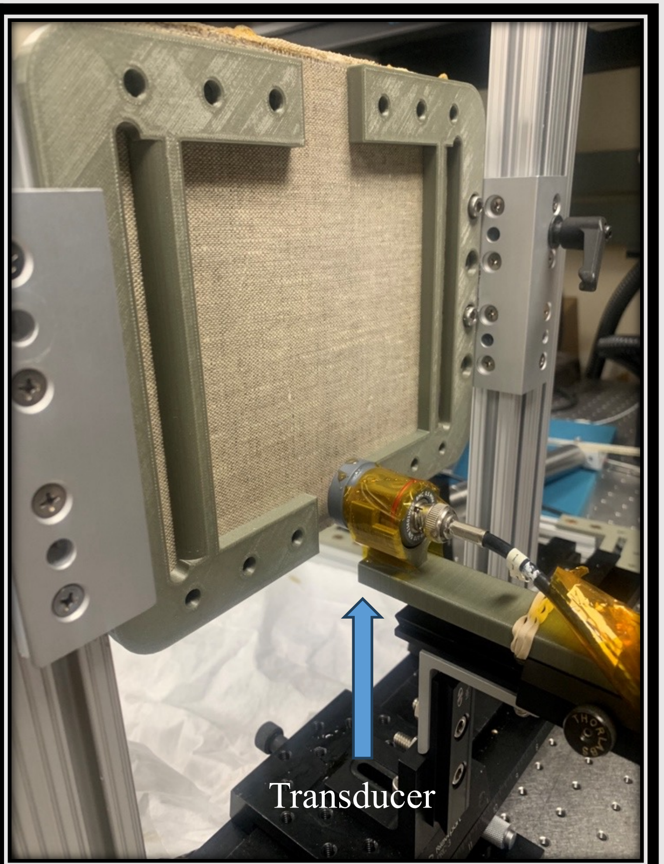
Laser Doppler Vibrometer Bouligand Flax Scan

Objective: Characterize the Flax fiber composite by interpreting its interaction with guided waves

Parameters	
	0.5 MHz Transducer
	Couplant: Honey
	Chirp Wave Form (20kHz – 1MHz)
	Full Field Scan (4in x 6in)
	Scan Time 1.5 Weeks



Class II Laser Doppler Vibrometer



Flax Panel in contact w/ transducer

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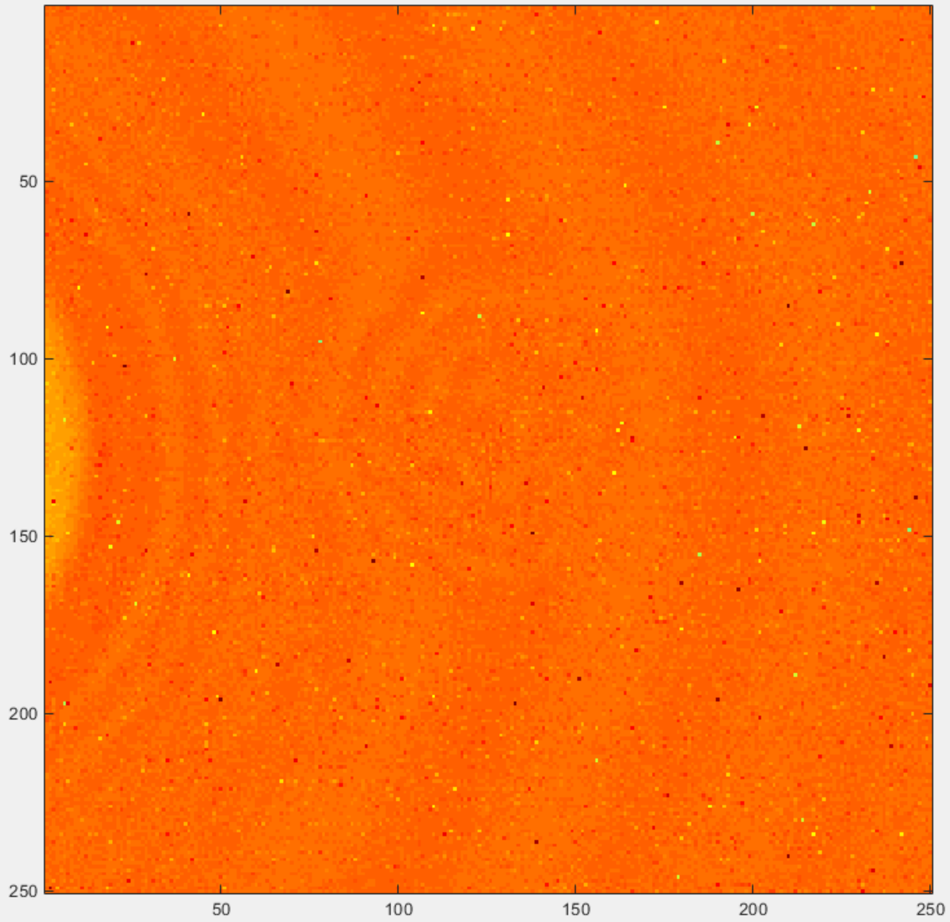
Example: Pristine Carbon Fiber Plate



Video Credit: Peter Juarez

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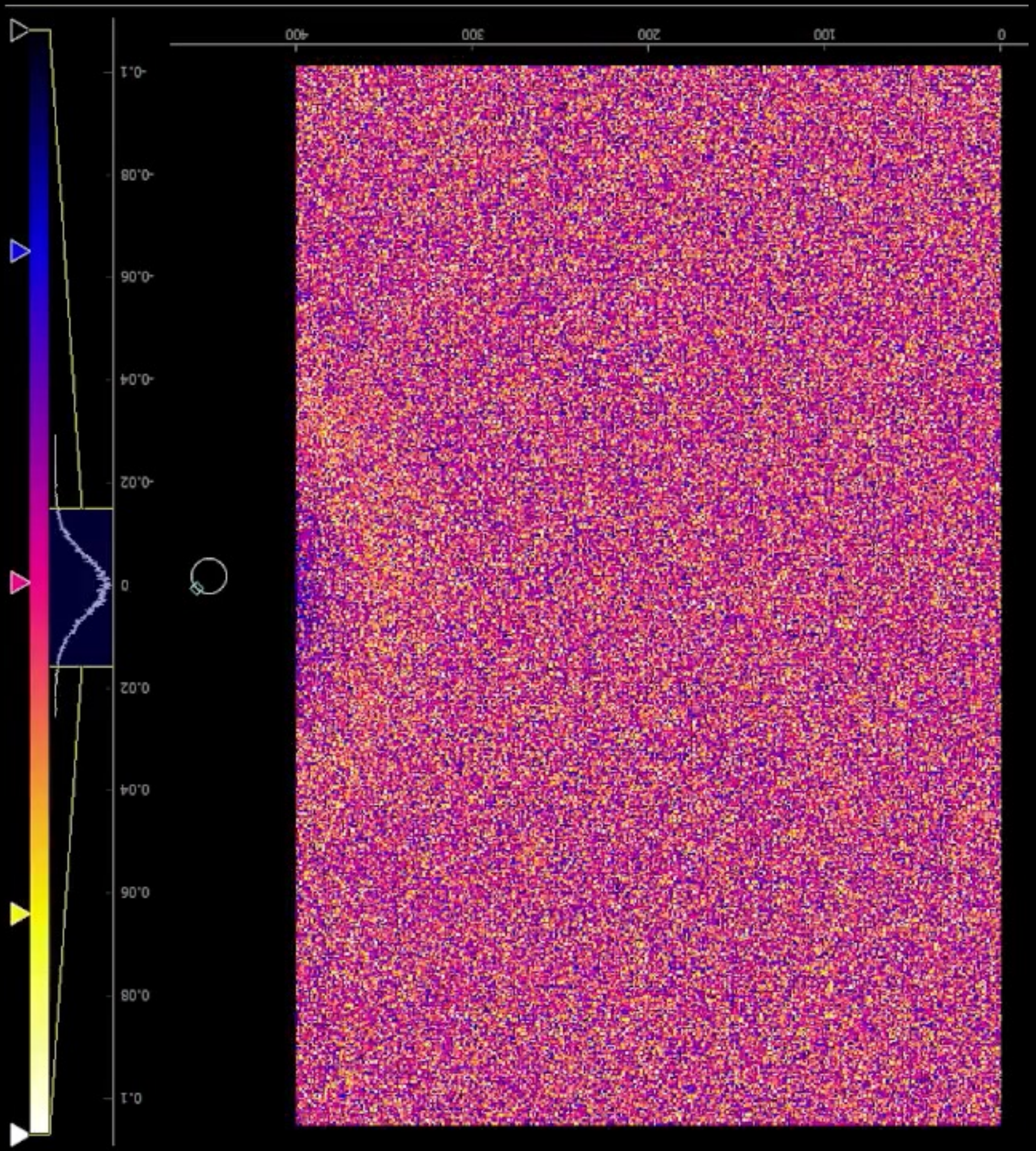

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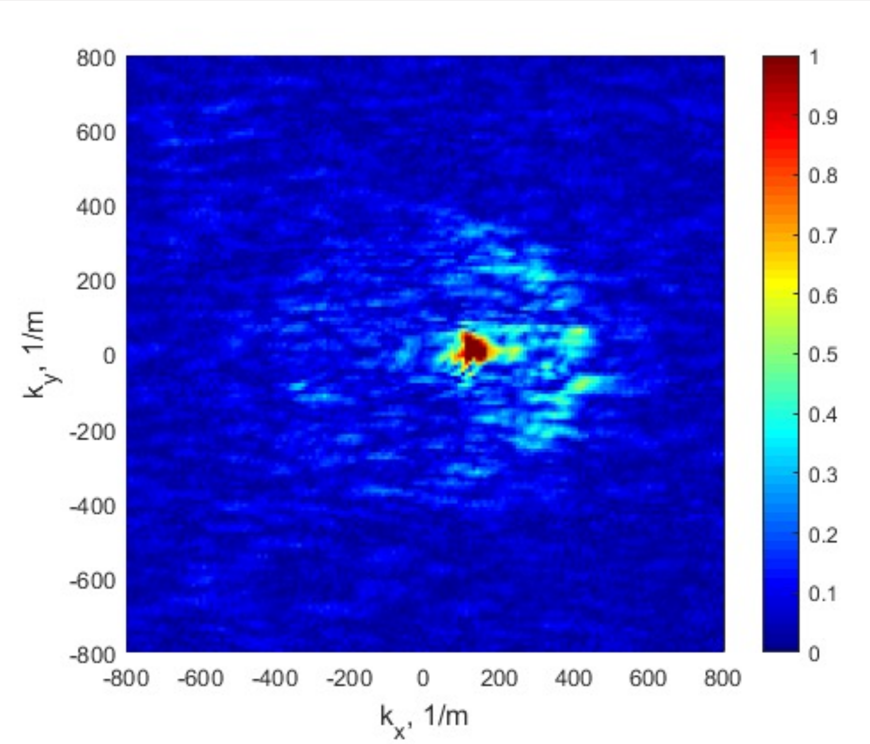
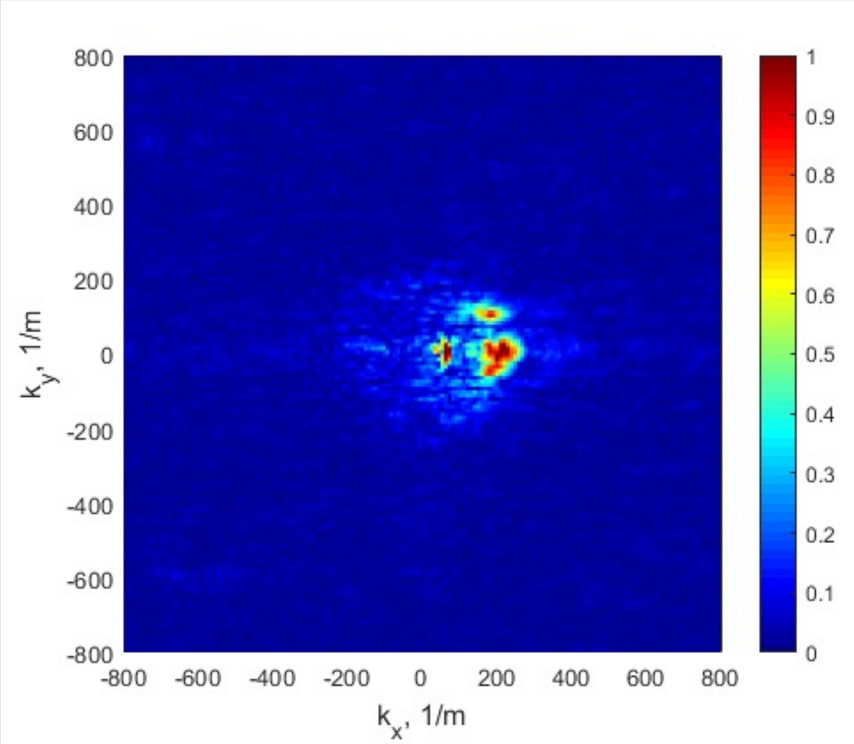
Bouligand Flax Composite wavenumber frequency domain analysis



200KHz

Bouligand Flax Composite wavenumber frequency domain analysis



100KHz

These images show a measurement of wavenumber at a specific frequency and what direction they are travelling.

$$\text{Real(Wavenumber k)} = \frac{1}{Wavelength}$$

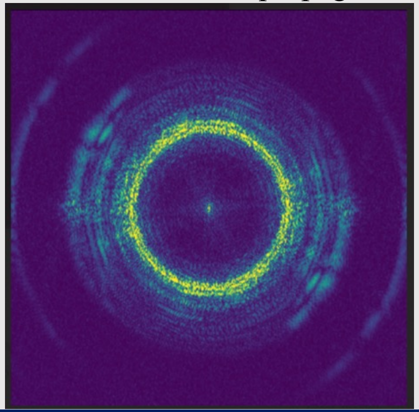
3D FFT

$$\mathrm{v_z}(\mathrm{x,y,t}) * \mathrm{w}(\mathrm{x,y,t};\alpha) \longrightarrow V_z(k_x, k_y, f)$$

$w(x,y,t;\alpha)$ 3D Tukey window with
α = cosine taper (10%)
$\mathrm{v_z}$ = velocity
V_z = velocity, FFT magnitude
(x,y): spatial location on plate in meters

t = time in seconds
f = frequency in cycles/sec
k_y = y-dir wavenumber in cycles/meter
k_x = x-dir wavenumber in cycles/meter

Ex: Wavenumber frequency domain full wave propagation



Picture Credit: Peter Juarez

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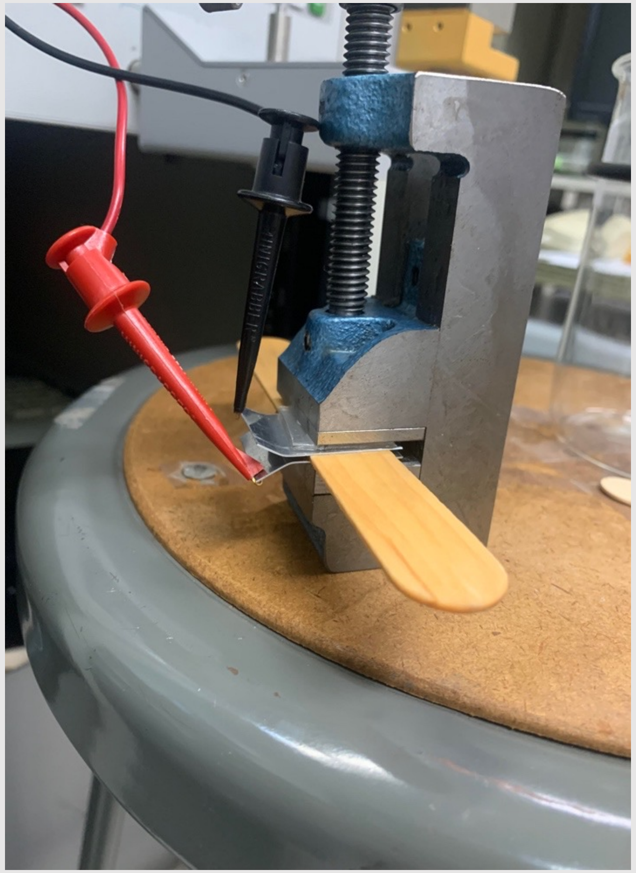
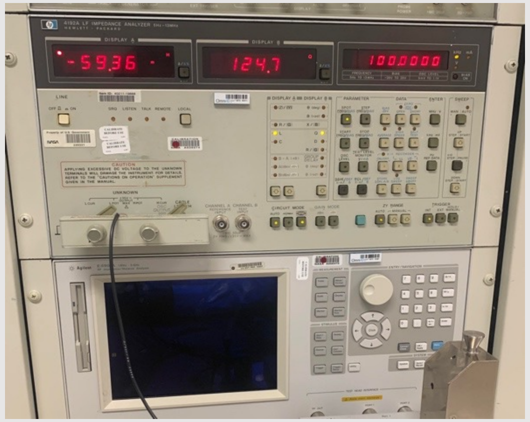
LCR Measurements of Moisture Content in Popsicle Sticks

Aluminum plates used to conduct electricity through specimen



(Plastic plates placed in-between aluminum & vice)

LCR Measurement System



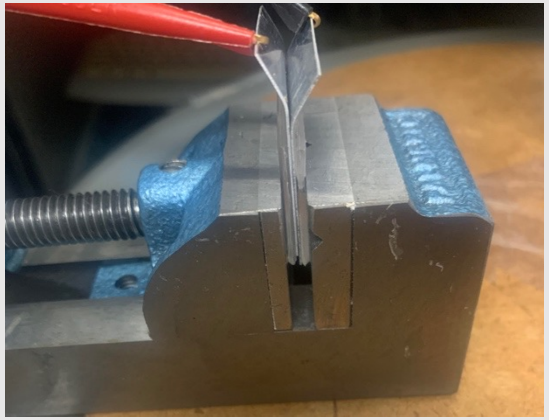


Plate to plate measurements

Parameters

- Studied the electrical properties of natural wooden fibers when soaked in water at various intervals of time using LCR Meter

- Soaking Times: 15min, 30min, 45min, 60min
- Specimen: Popsicle Stick
- Base Weight: 2.5543± 0.02 Grams
- Specimen Thickness: 0.060 Inch
- Measurement Plates: Thin Aluminum 1/100th inch
- Area Per Plate: 1.090 Inch x 0.788 Inch
- Frequency Sweeps from 5 Hz – 13 MHz

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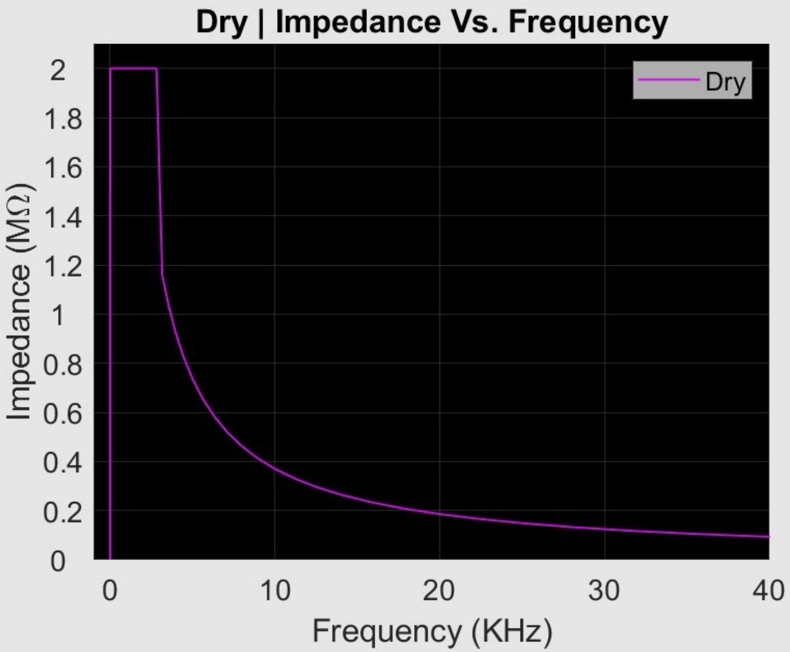
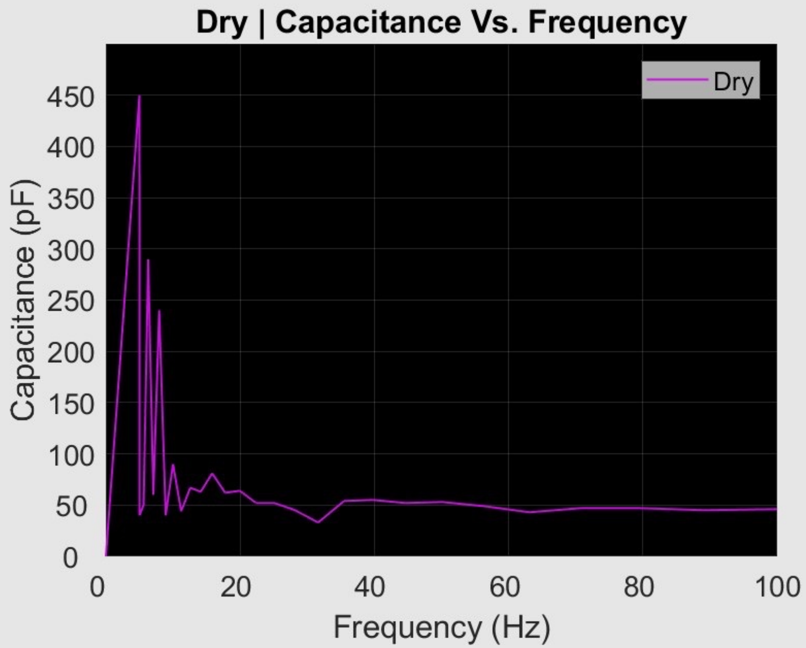
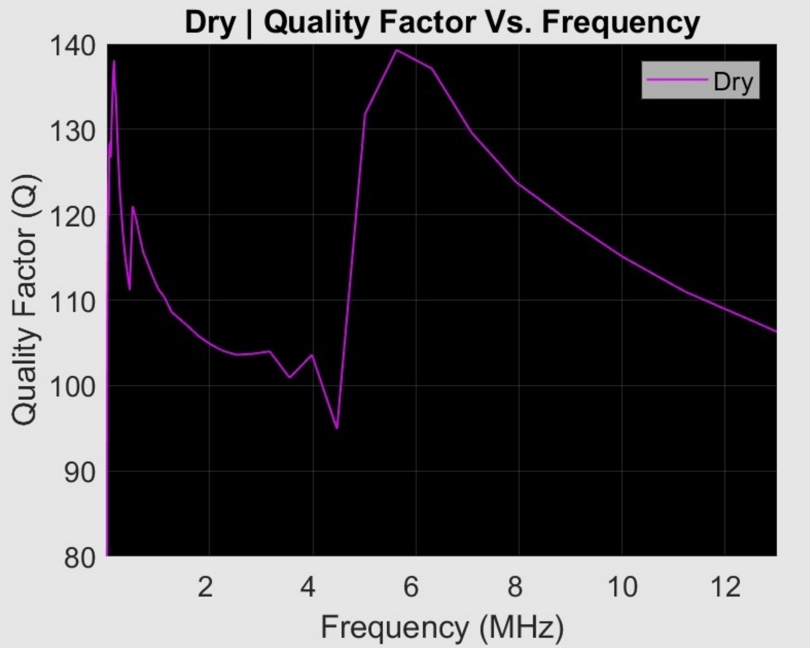
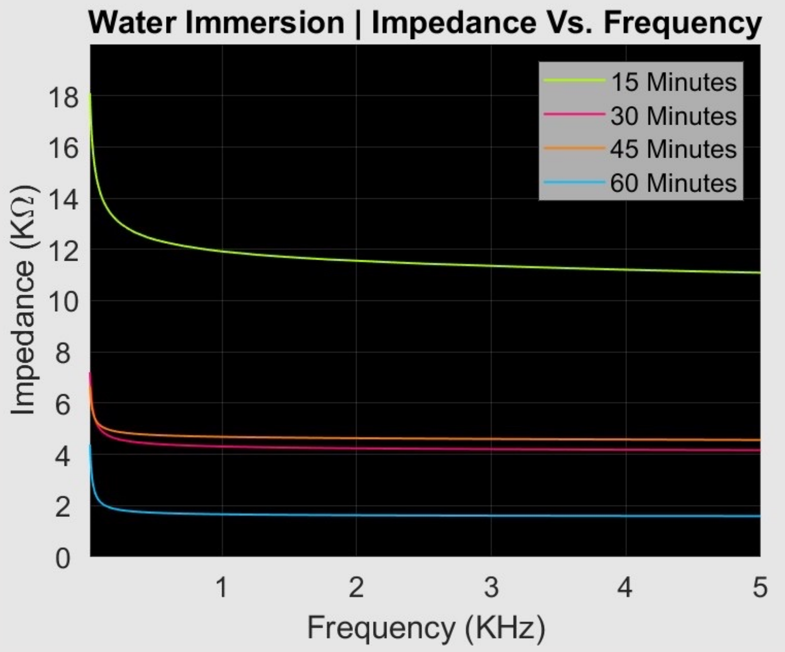
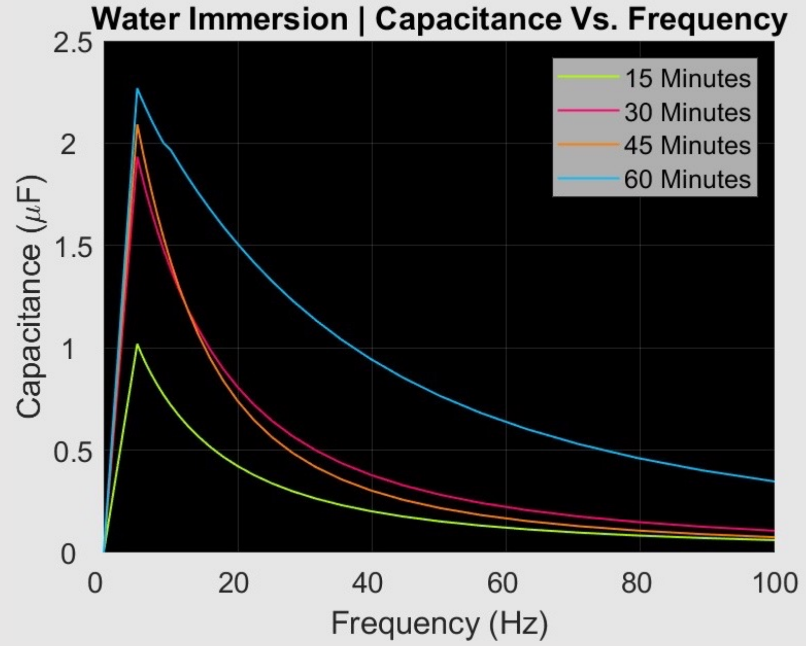
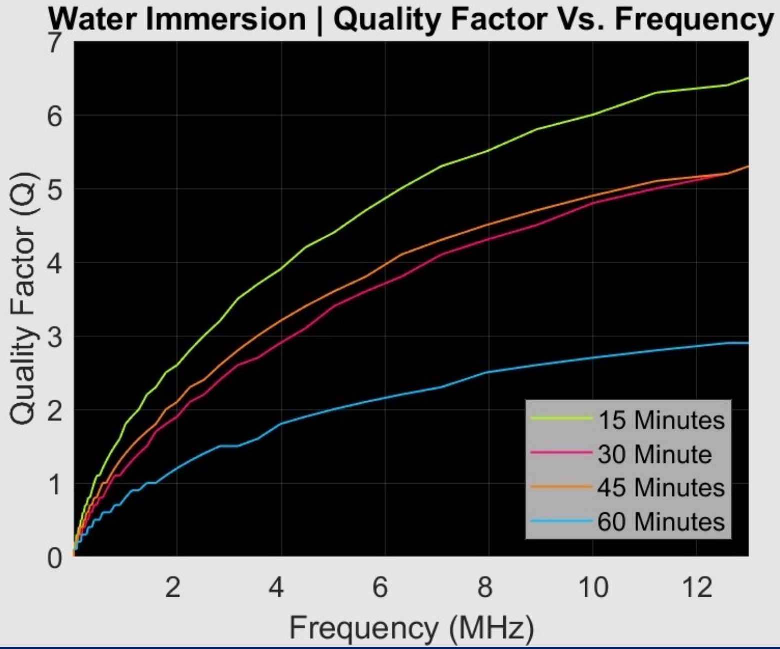

Dry | Impedance Vs. Frequency
Dry
Impedance (MΩ)
Frequency (KHz)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40

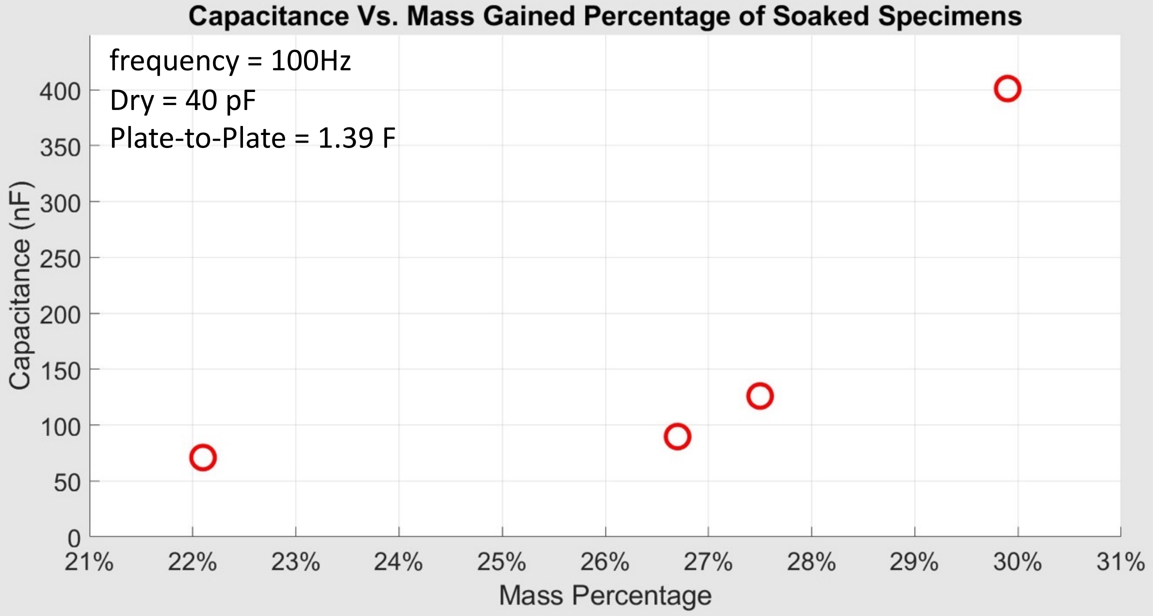

Dry | Capacitance Vs. Frequency
Dry
Capacitance (pF)
Frequency (Hz)
0
50
100
150
200
250
300
350
400
450
0
20
40
60
80
100

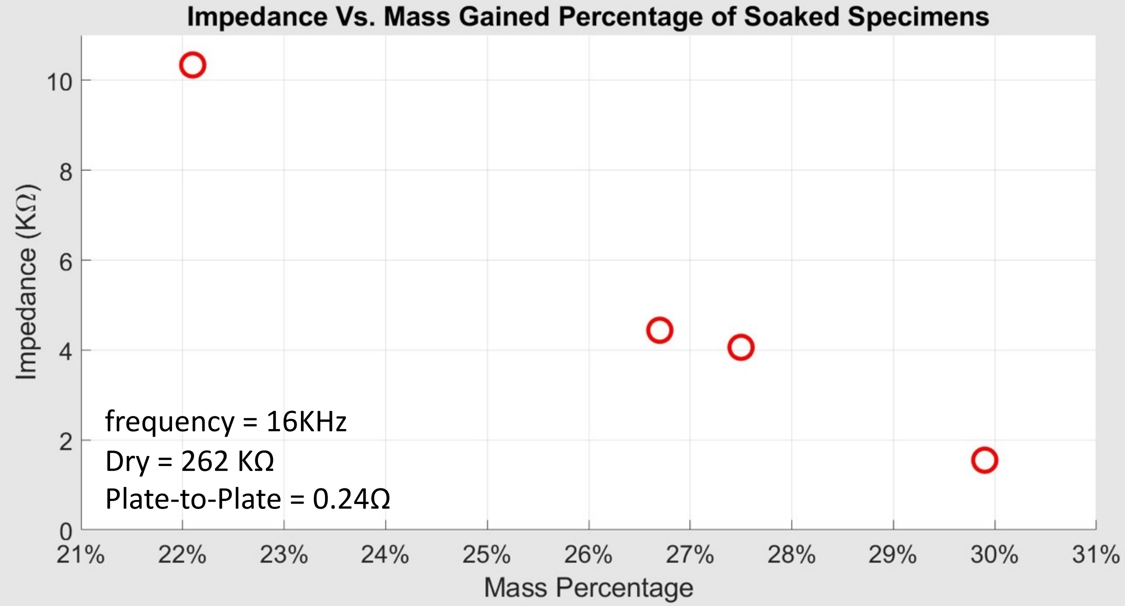

Dry | Quality Factor Vs. Frequency
Dry
Quality Factor (Q)
Frequency (MHz)
80
90
100
110
120
130
140
2
4
6
8
10
12

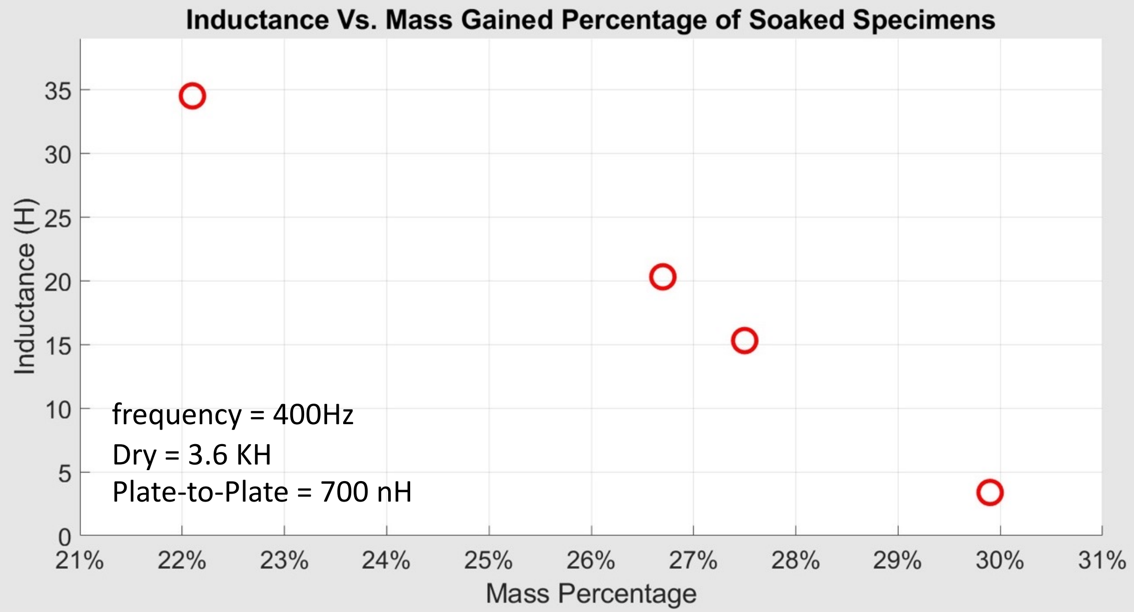

Water Immersion | Impedance Vs. Frequency
15 Minutes
30 Minutes
45 Minutes
60 Minutes
Impedance (KΩ)
Frequency (KHz)
0
2
4
6
8
10
12
14
16
18
1
2
3
4
5

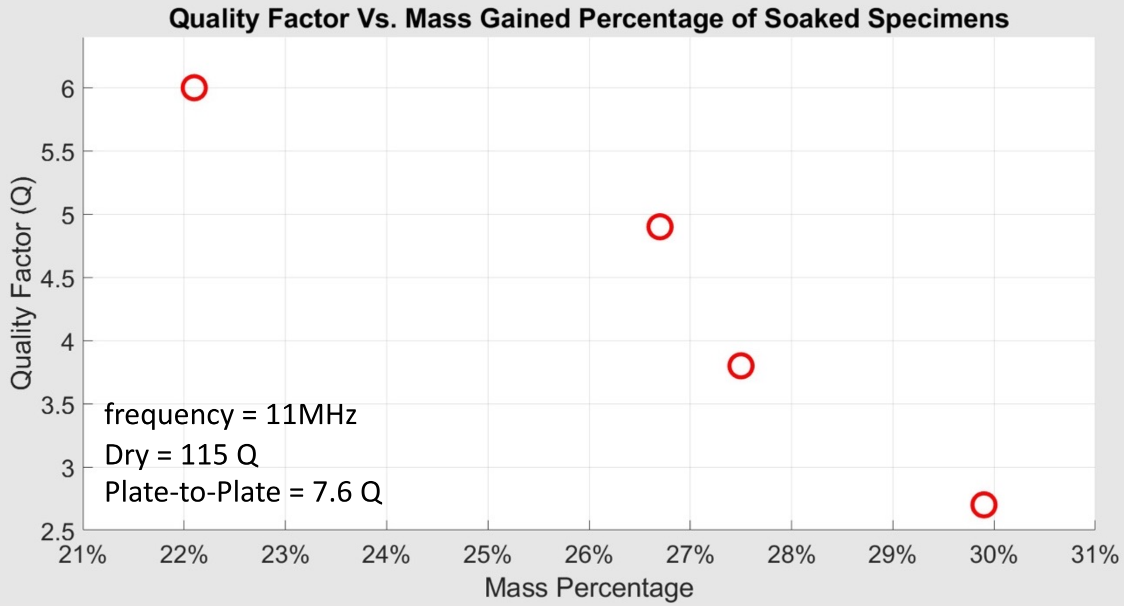

Water Immersion | Capacitance Vs. Frequency
15 Minutes
30 Minutes
45 Minutes
60 Minutes
Capacitance (μF)
Frequency (Hz)
0
0.5
1
1.5
2
2.5
0
20
40
60
80
100


Water Immersion | Quality Factor Vs. Frequency
15 Minutes
30 Minute
45 Minutes
60 Minutes
Quality Factor (Q)
Frequency (MHz)
0
1
2
3
4
5
6
7
2
4
6
8
10
12


Capacitance Vs. Mass Gained Percentage of Soaked Specimens
frequency = 100Hz
Dry = 40 pF
Plate-to-Plate = 1.39 F
Capacitance (nF)
0
50
100
150
200
250
300
350
400
21%
22%
23%
24%
25%
26%
27%
28%
29%
30%
31%
Mass Percentage


Impedance Vs. Mass Gained Percentage of Soaked Specimens
Impedance (KΩ)
0
2
4
6
8
10
frequency = 16KHz
Dry = 262 KΩ
Plate-to-Plate = 0.24Ω
21%
22%
23%
24%
25%
26%
27%
28%
29%
30%
31%
Mass Percentage


Inductance Vs. Mass Gained Percentage of Soaked Specimens
Inductance (H)
0
5
10
15
20
25
30
35
frequency = 400Hz
Dry = 3.6 KH
Plate-to-Plate = 700 nH
21%
22%
23%
24%
25%
26%
27%
28%
29%
30%
31%
Mass Percentage


Quality Factor Vs. Mass Gained Percentage of Soaked Specimens
Quality Factor (Q)
2.5
3
3.5
4
4.5
5
5.5
6
frequency = 11MHz
Dry = 115 Q
Plate-to-Plate = 7.6 Q
21%
22%
23%
24%
25%
26%
27%
28%
29%
30%
31%
Mass Percentage

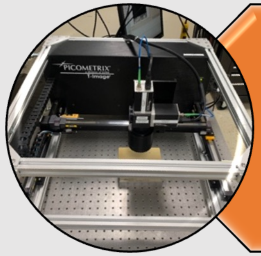
Takeaways

Established nondestructive test methods and structural health monitoring approaches for natural fiber composites

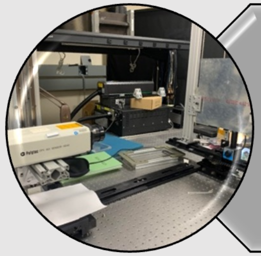
Characterized acoustic and electric properties

Gained familiarity with ultrasonic, laser doppler vibrometer, and terahertz approaches

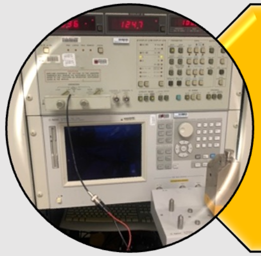
Supported test development for various application of nondestructive evaluation.



Terahertz Time-Domain Spectroscopy



Laser Doppler Vibrometry



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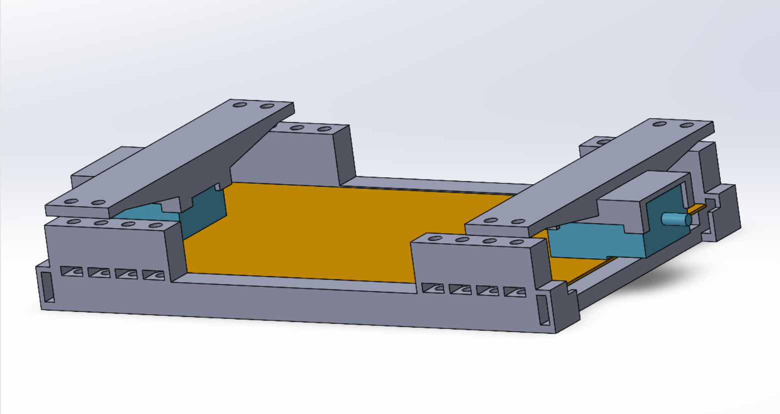
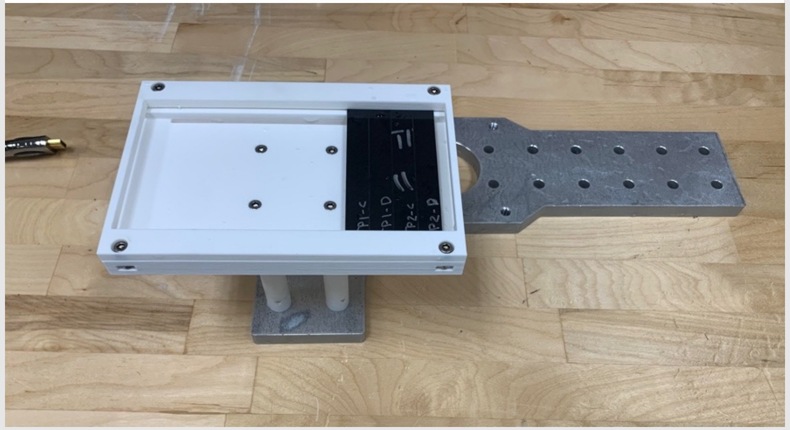
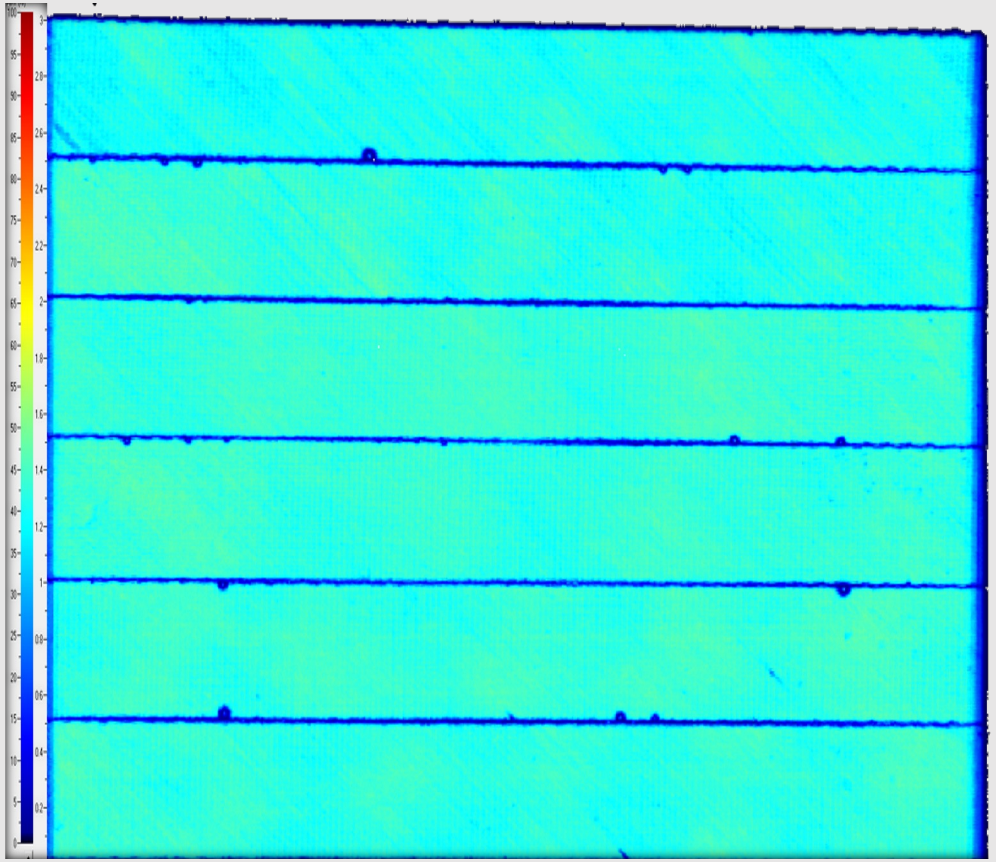
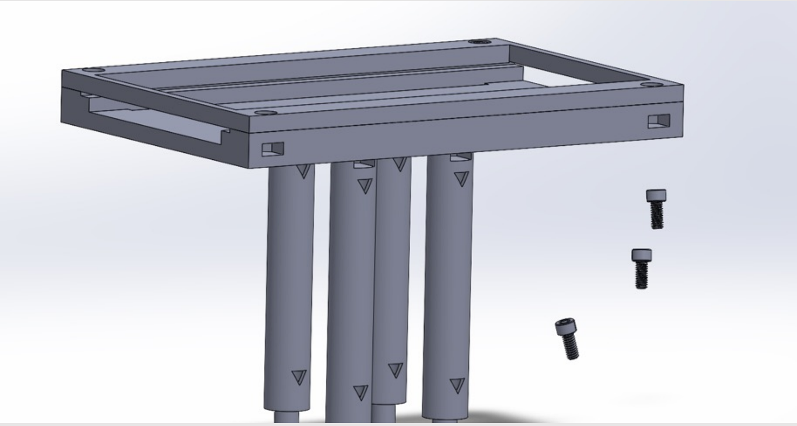








Composite Technologies for Exploration Part A (CTE-A)

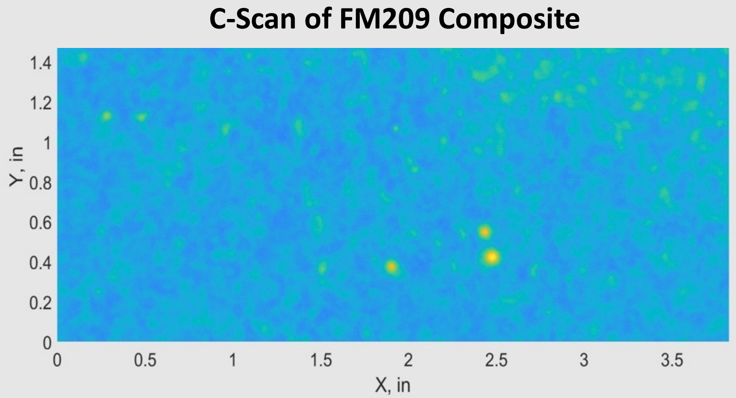
Integrated Sensing Objective: Develop sensing techniques to detect microcracking in composite materials when exposed to cryogenic temperatures.

Contributions: Designed test fixtures for repeatability of data collection, established Baseline data for thermoplastic, and thermoset composites.

Transformational Tools & Technologies (TTT)

Objective: to develop an NDE technique to measure bond strength

Contributions: Did 2D C-scan of FM209, analyzed waveforms, determined the probability distribution of key acoustic properties of the adhesive joint.



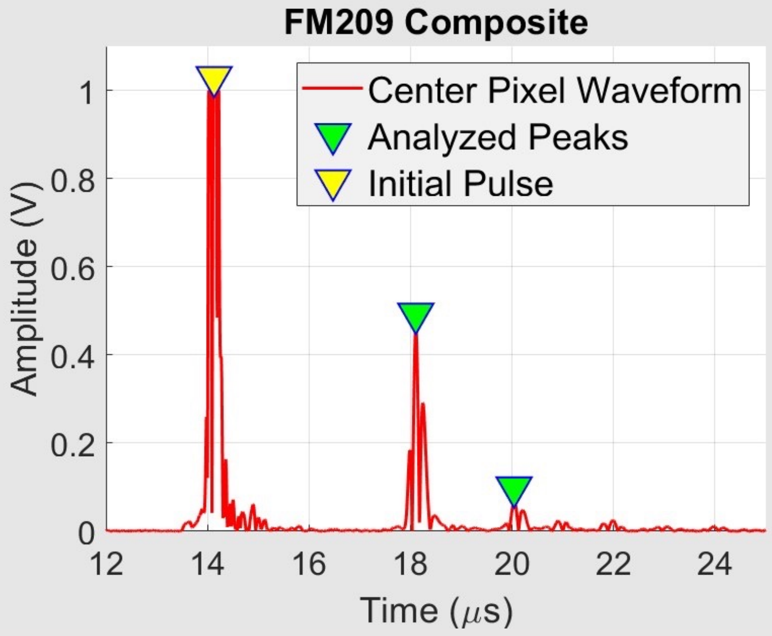
Number of Pixels: 188k

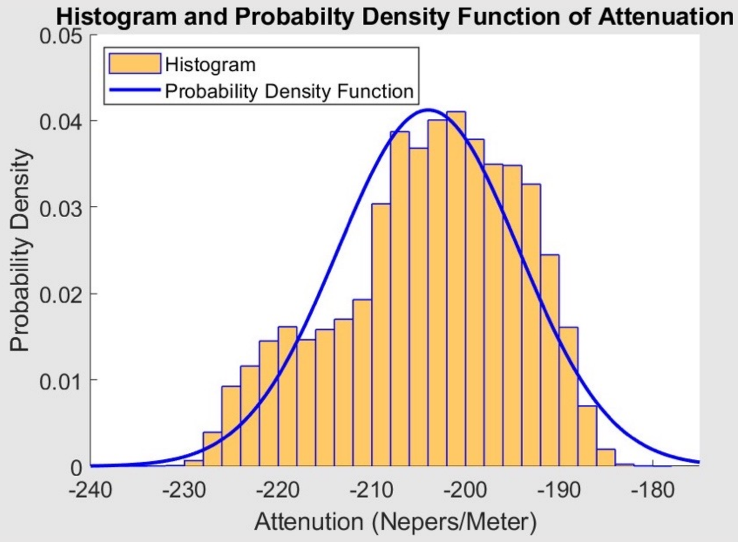
Mean Attenuation (μ): -203.9 Nepers/Meter

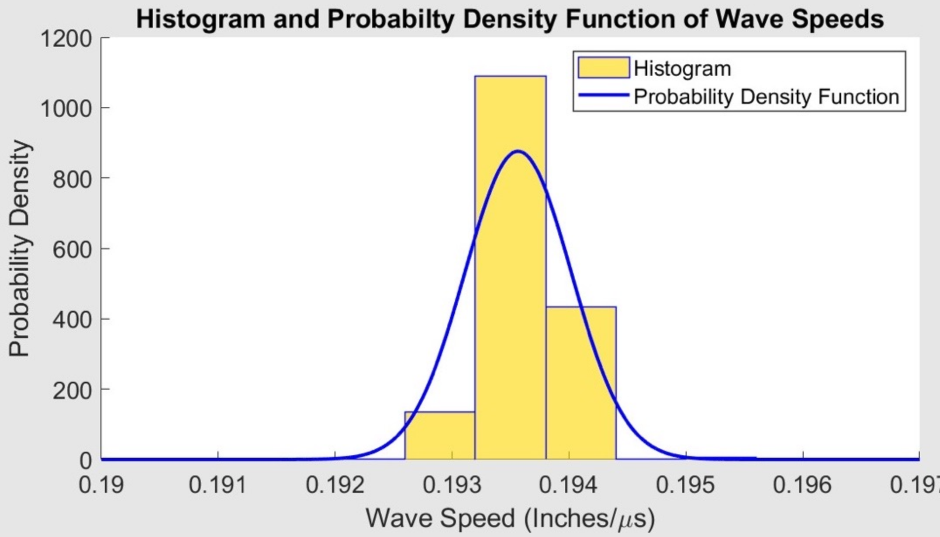
Standard Deviation (σ) : 9.67 Nepers/Meter

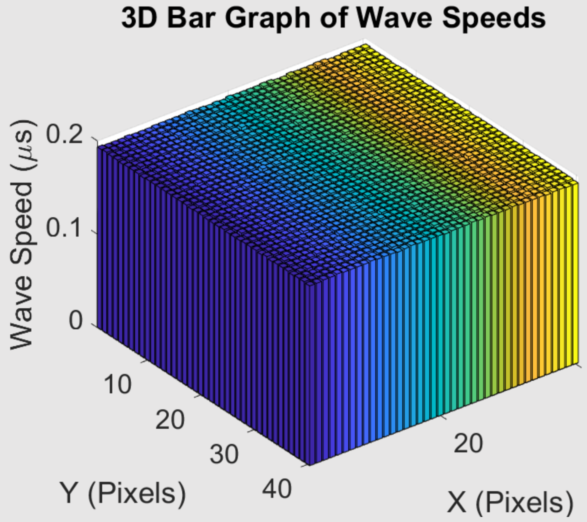
Mean Wave Speed (μ) : 0.194 Inches/Microsecond

Standard Deviation (σ) : 0.456e-03 Inches/Microsecond









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Akbar Eslami | Dept. Chair of Engineering & Technology

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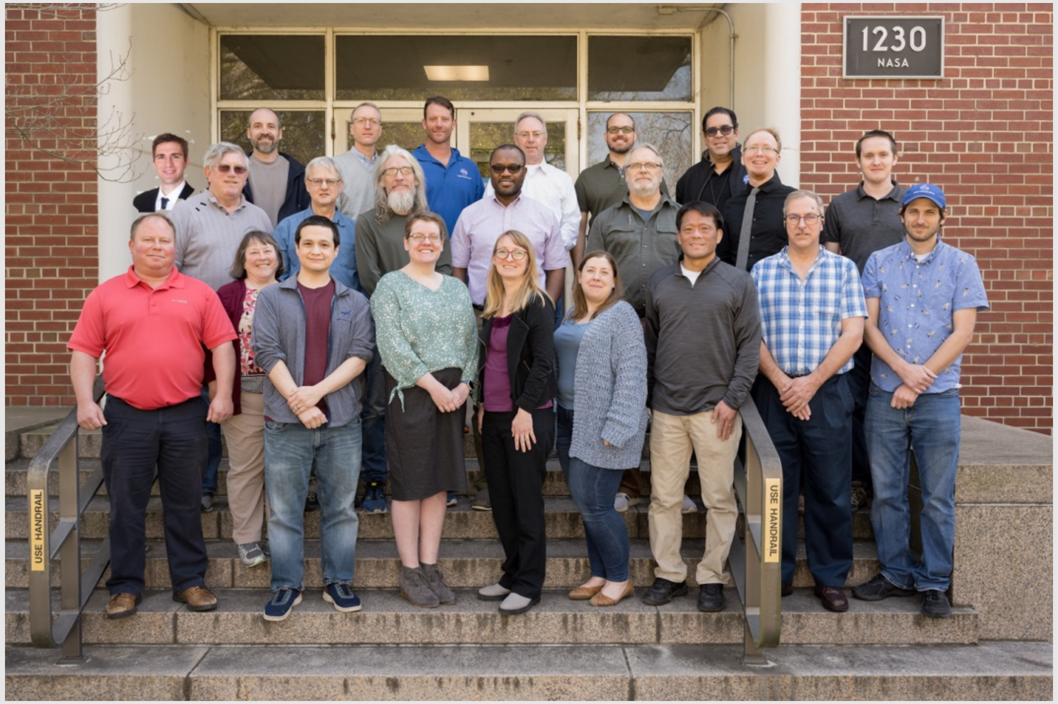
Cara Leckey | NESB Branch Head

Nondestructive Evaluations Science Branch Members



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