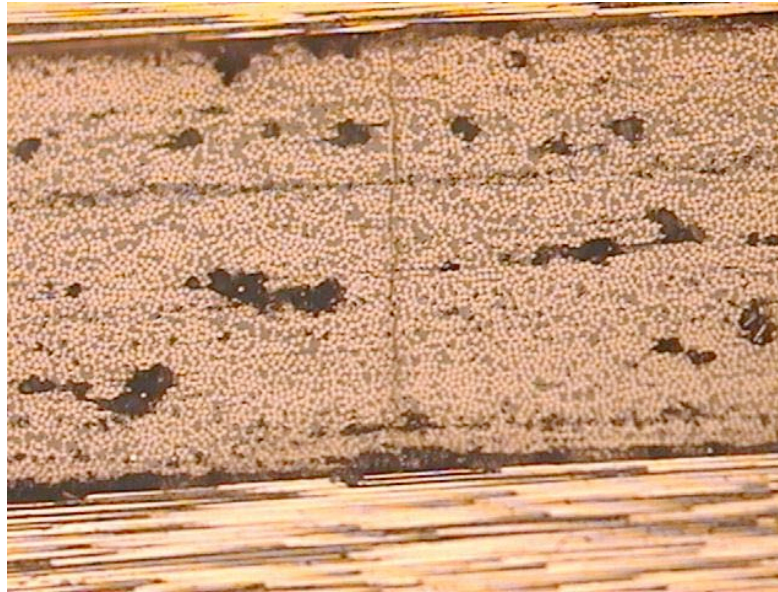


Fatigue Crack and Porosity Measurement in Composite Materials by Thermographic and Ultrasonic Methods



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OUTLINE

- **PURPOSE**

Detect thermo-mechanically induced intra-ply fatigue microcracking and manufactured porosity in unlined composite pressure vessels

- **DEFECT DESCRIPTIONS**

Porosity

Microcracking

- **THERMOGRAPHY**

Overview of technique

Strengths and Weaknesses

Examples of its use for porosity detection

- **RESONANT ULTRASOUND SPECTROSCOPY**

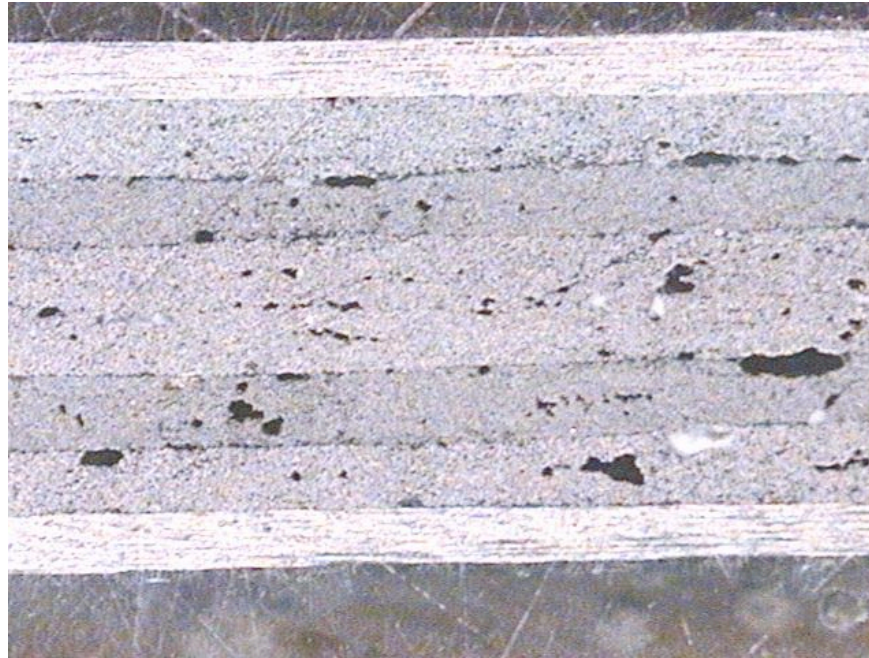
Overview of technique

Strengths and Weaknesses

Examples of its use for microcracking detection

- **CONCLUSIONS**

DEFECT DESCRIPTIONS (Porosity)



Cause/Definition: Voids trapped within a laminate during the curing process due to off-gassing of the resin, air trapped between plies, improper cure schedule, etc.

DEFECT DESCRIPTIONS (Microcracking)



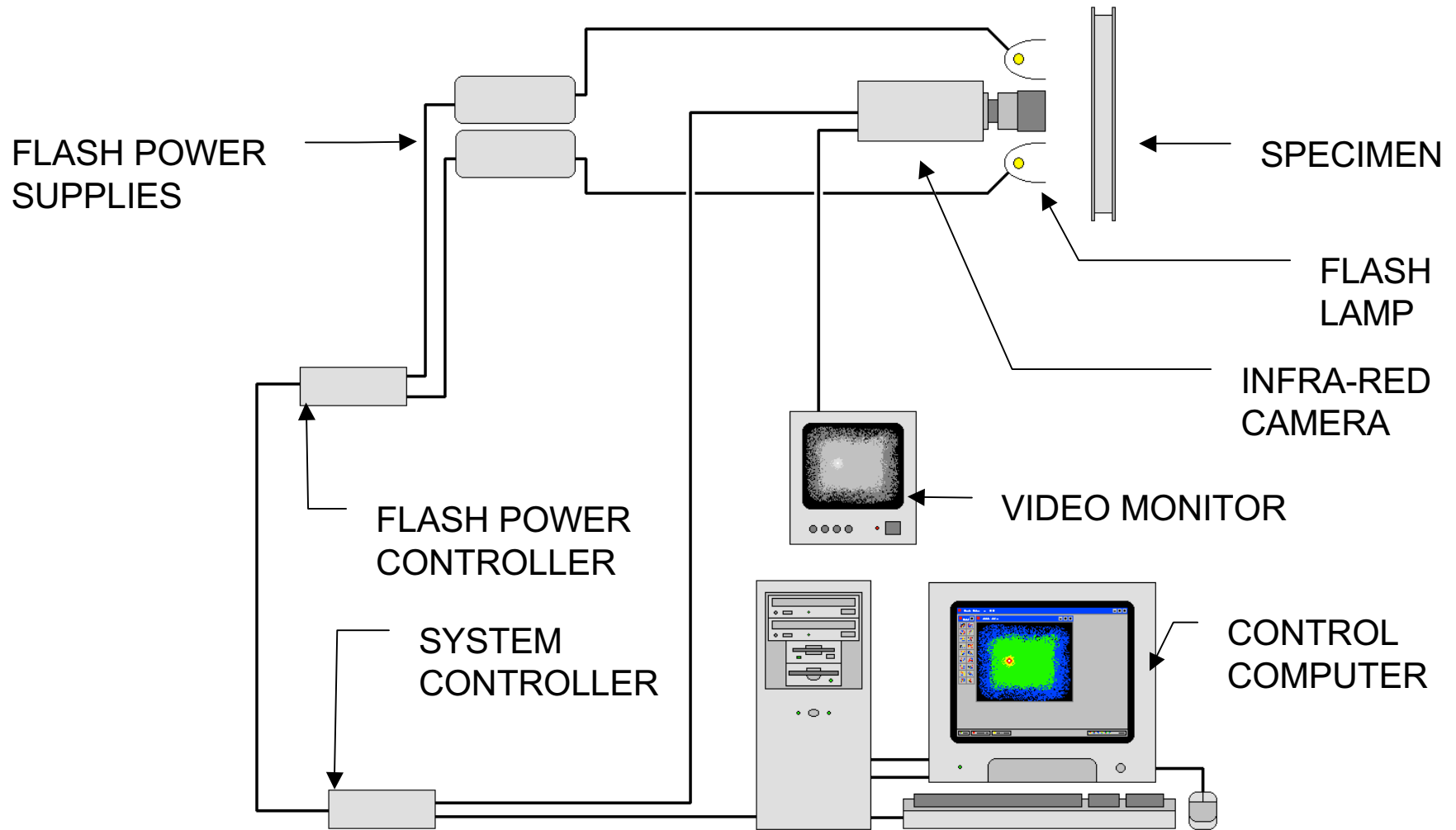
Cause/Definition: Cracking of the resin used to support the fibers in the laminate due to combined thermal “cryogenic” and mechanical loading.

THERMOGRAPHIC INSPECTION SYSTEM

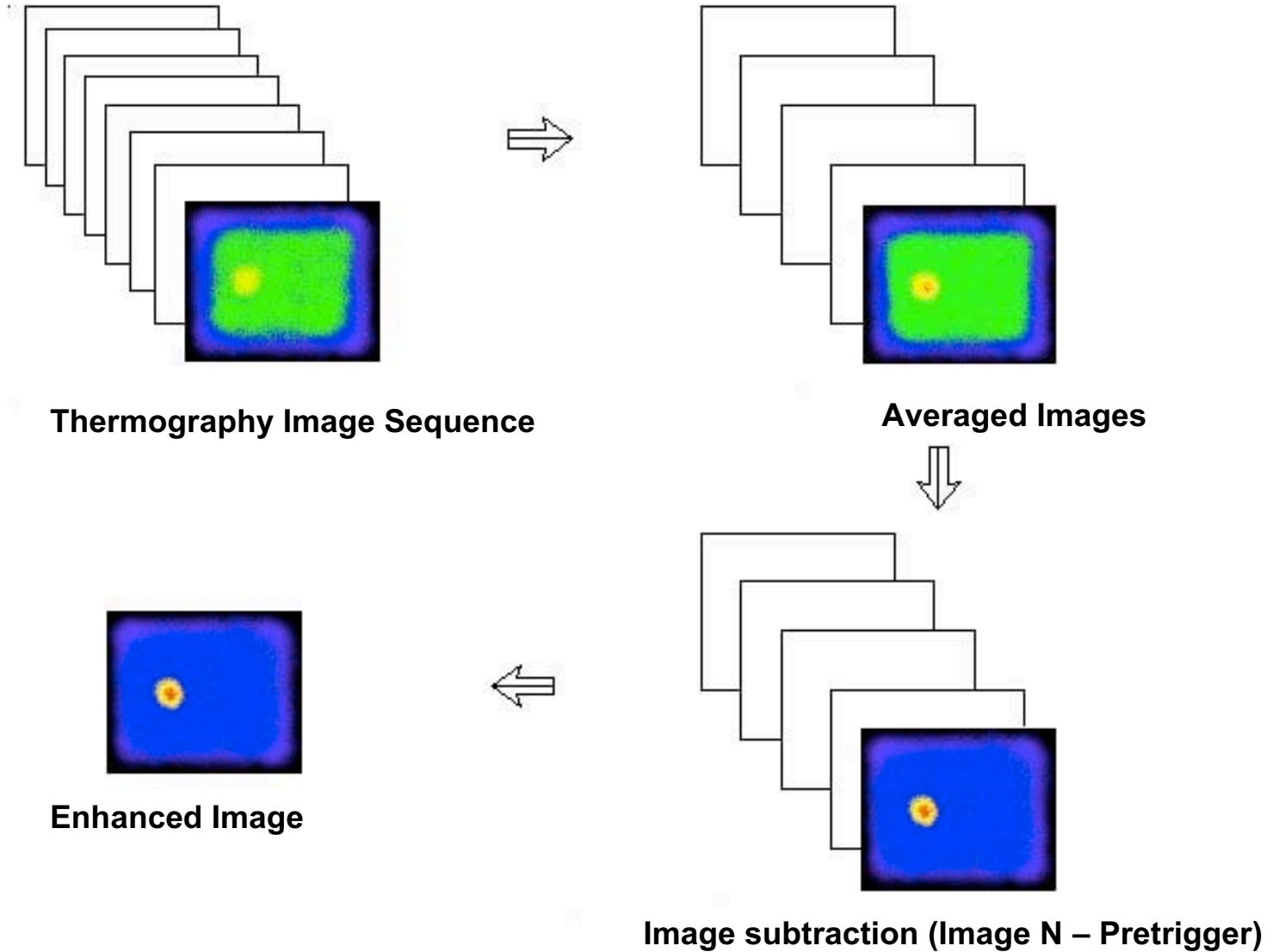
- **Imager: Indigo Merlin Mid**
- **Detector => Indium Antimonide**
- **Detector resolution => 256 x 312**
- **Spectral Response => 3 - 5 μm**
- **Sensitivity => 0.025 $^{\circ}\text{C}$ NE ΔT**
- **Software: ECHOTHERM[®] 32 (Thermal Wave Imaging, Inc.)**
- **Lens => 13 mm**



THERMOGRAPHIC ANALYSIS METHOD

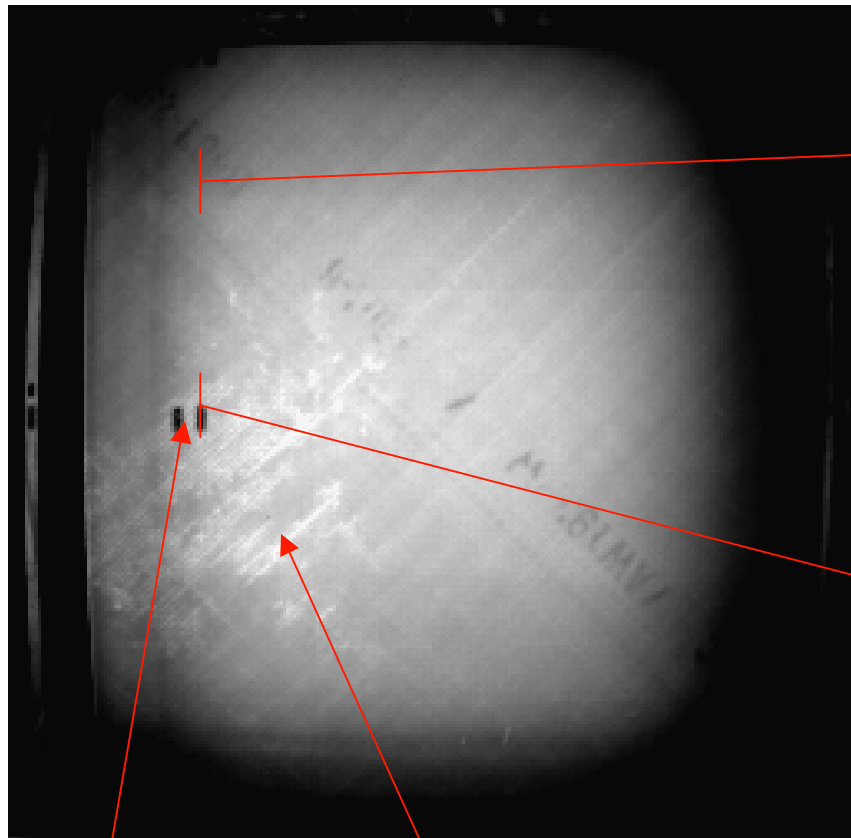


THERMOGRAPHIC ANALYSIS METHOD



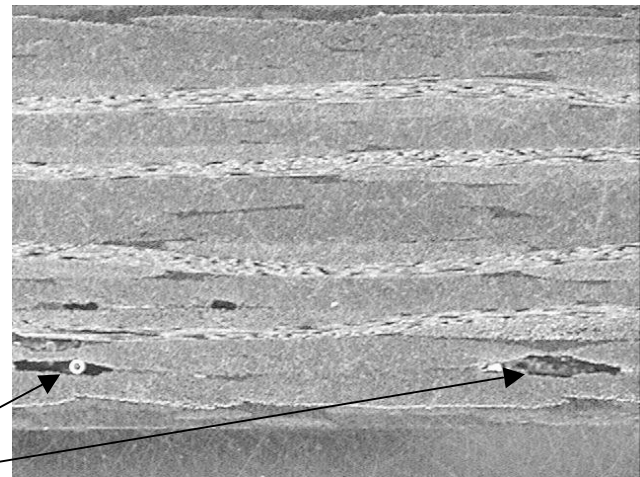
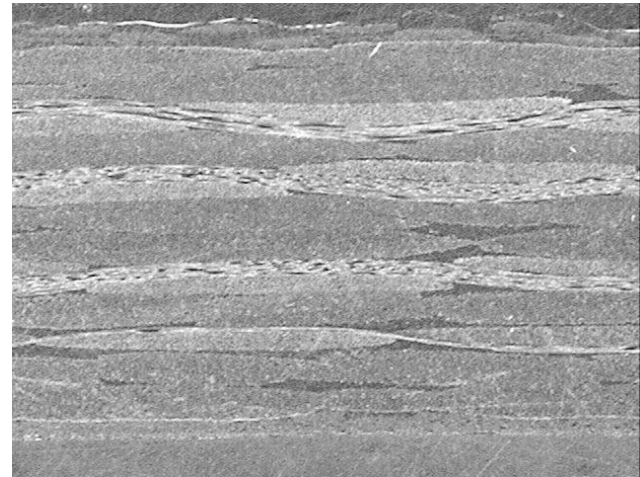
Clustered Porosity Detected Thermographically

8 inches



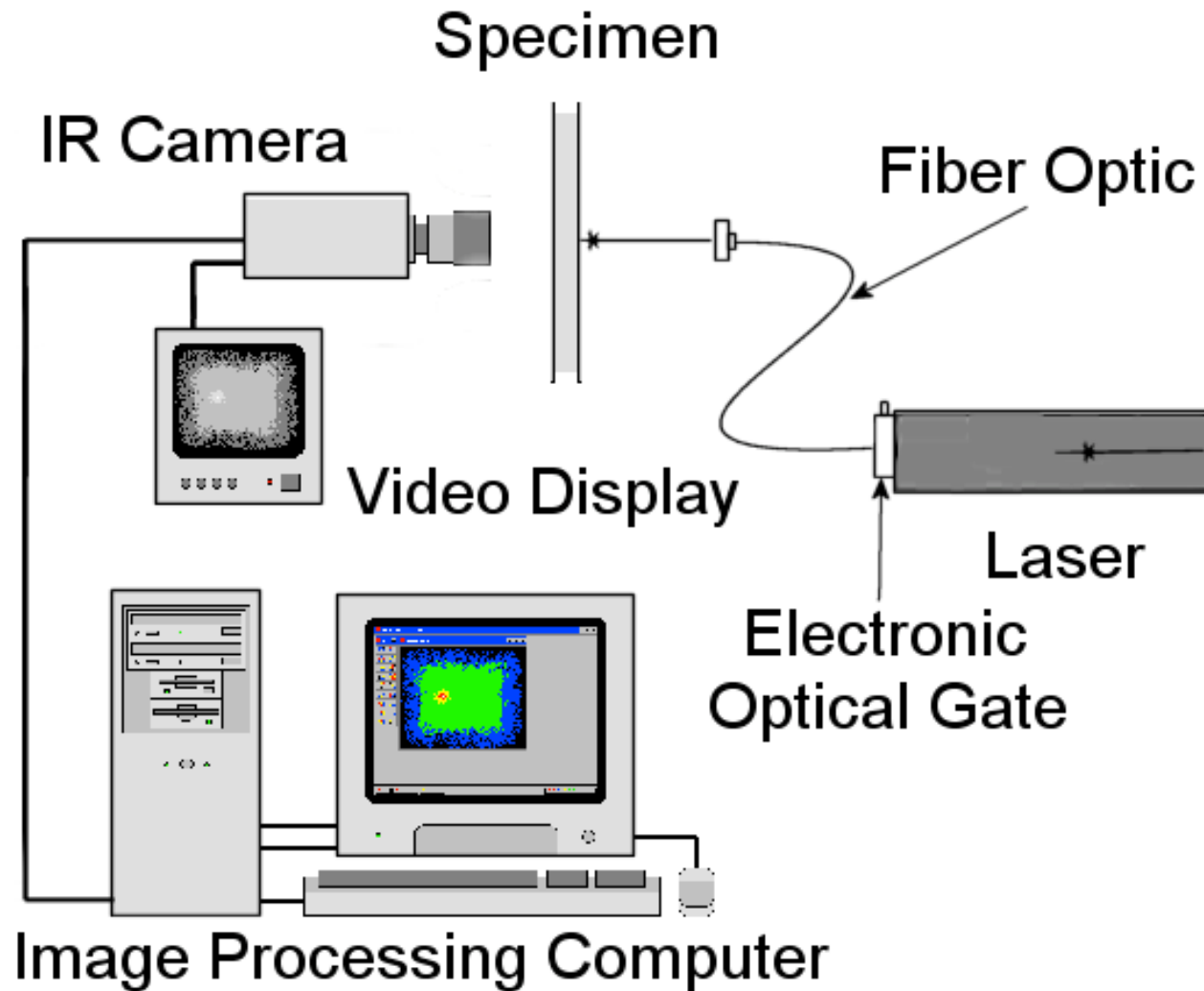
Lead foil markers

Porosity



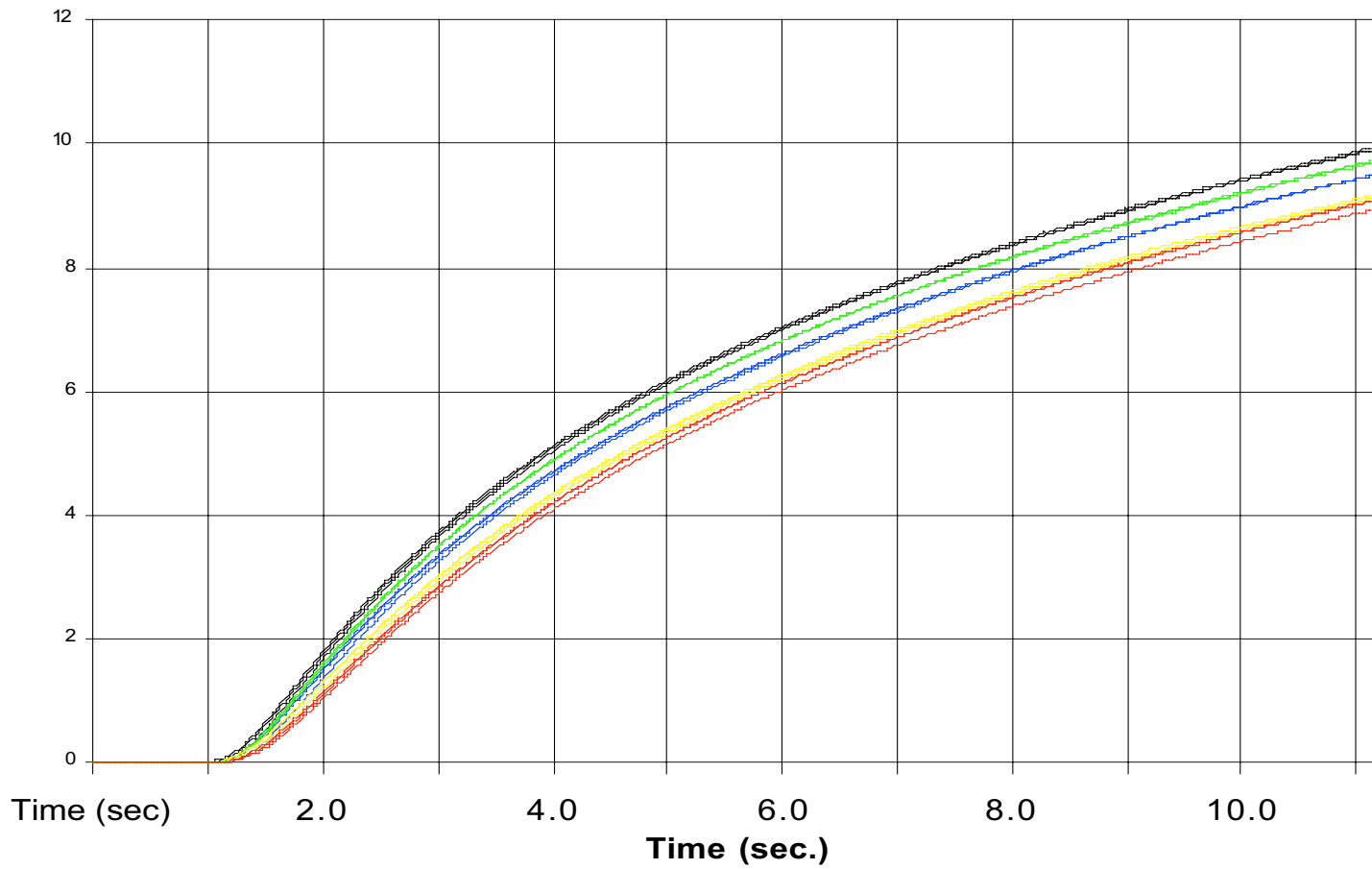
Porosity

THERMOGRAPHIC MATERIAL DEGRADATION TRACKING



THERMOGRAPHY TREND

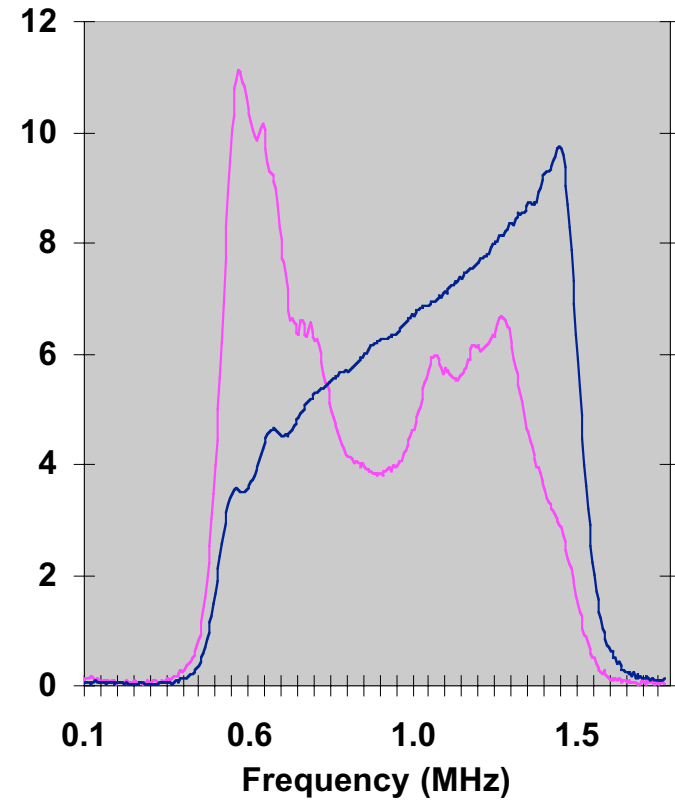
POROSITY IN GRAPHITE EPOXY



RESONANCE ULTRASOUND (ACOUSTO-ULTRASONICS)



Pulser
Receiver

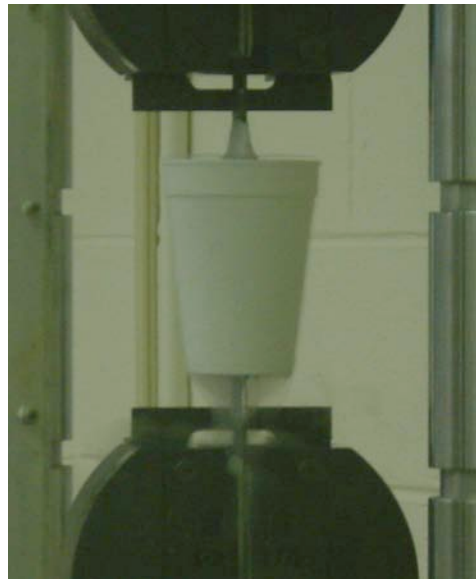


Typical Power Spectra

SAMPLE PREPARATION AND TESTING



SAMPLE PREPARATION



**CRYOGENIC TENSILE TESTING IN
LIQUID NITROGEN**

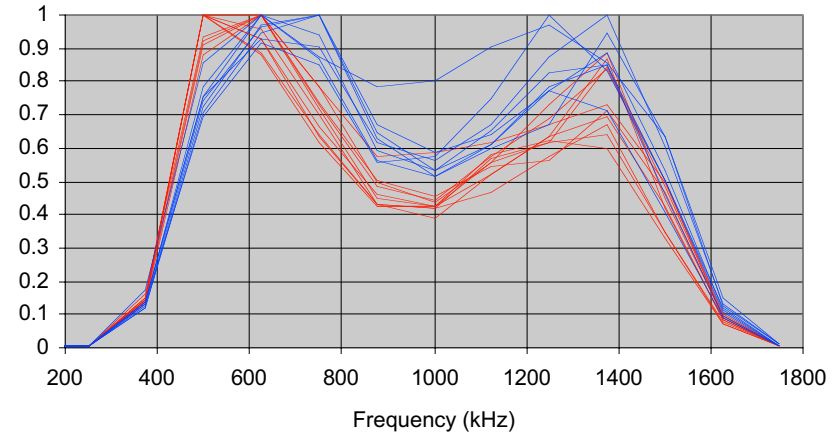


MICROCRACK COUNTING

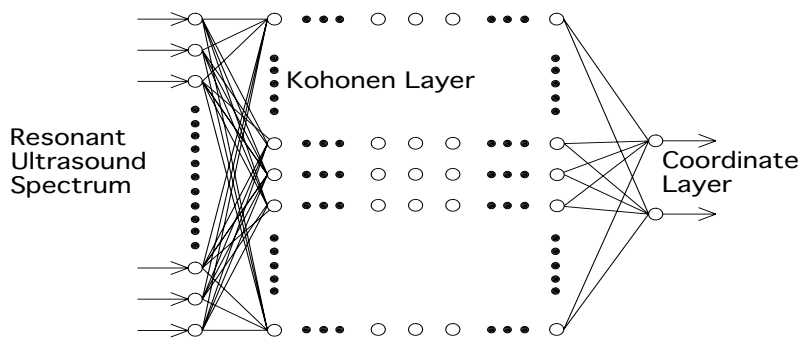
ANALYSIS (Self Organizing Map Neural Network)



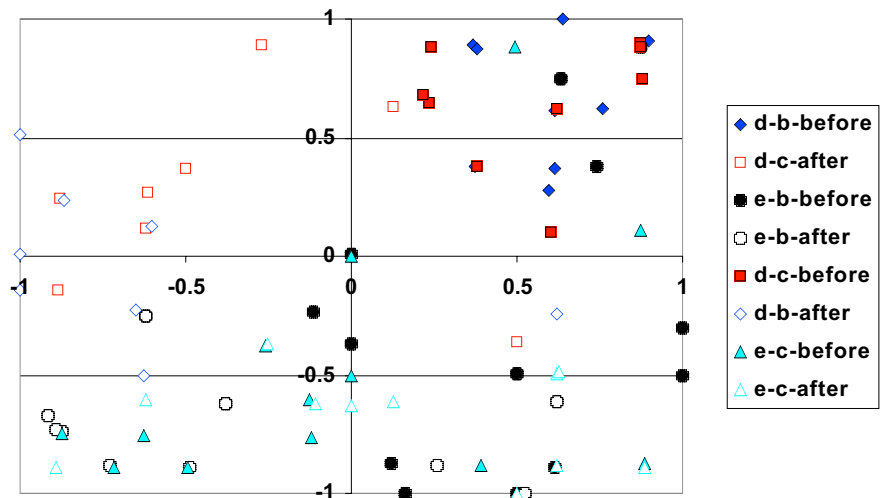
UltraSpec System



Energy distributions

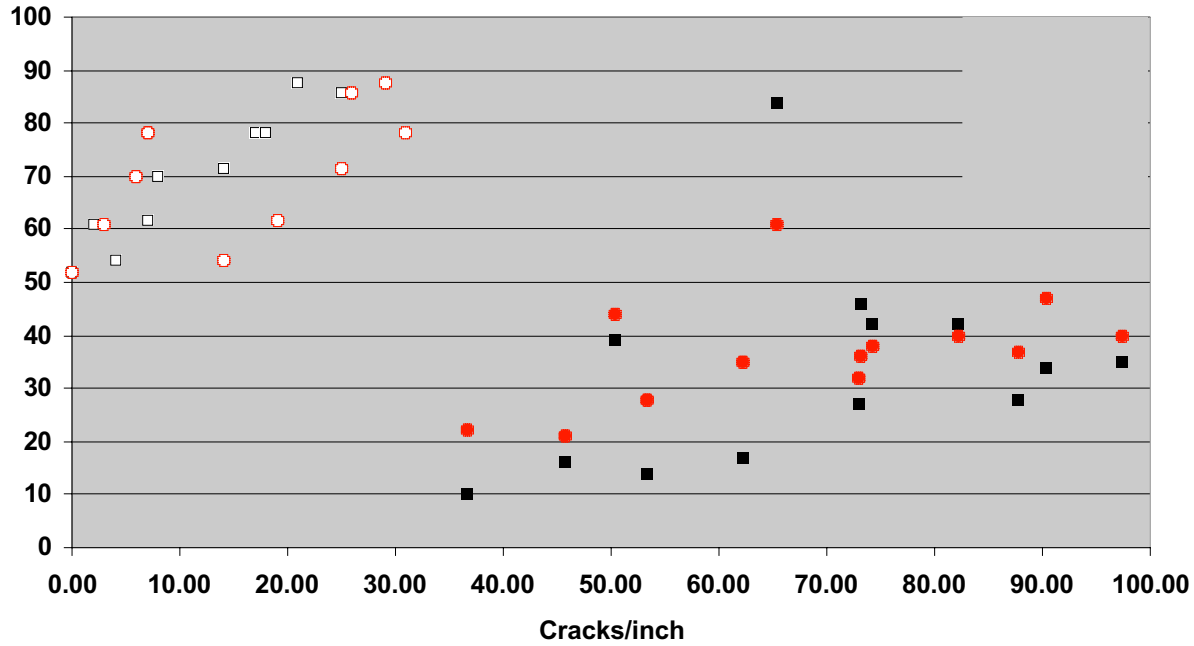


Self Organizing Map Neural Network



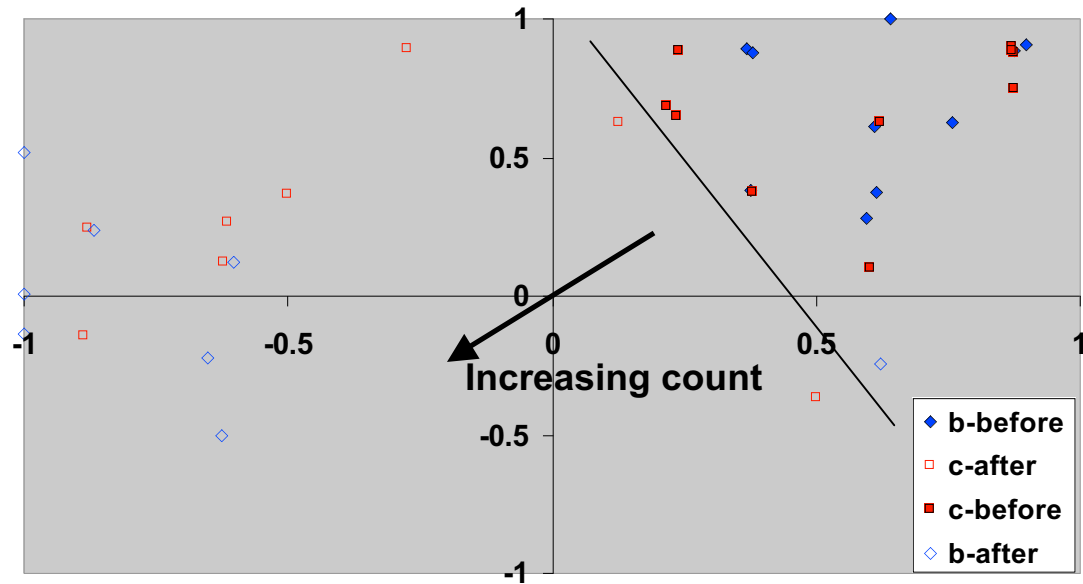
Neural Network Data Map

(0, 90, 0, 90)s SAMPLES

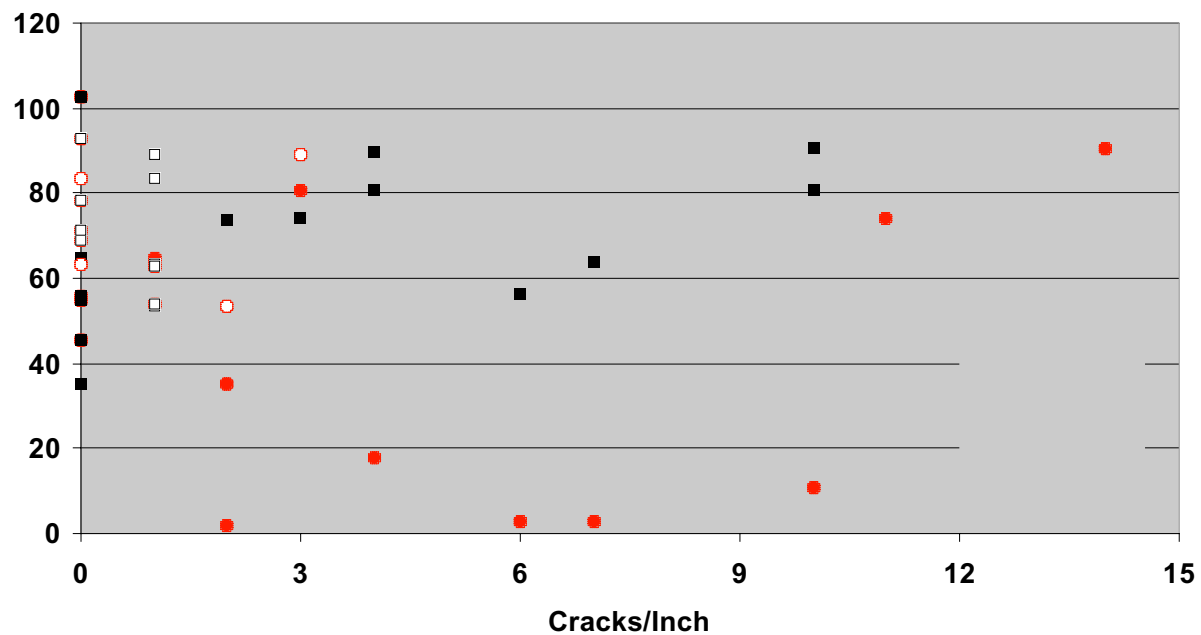


Microcrack Trend

Kohonen Map

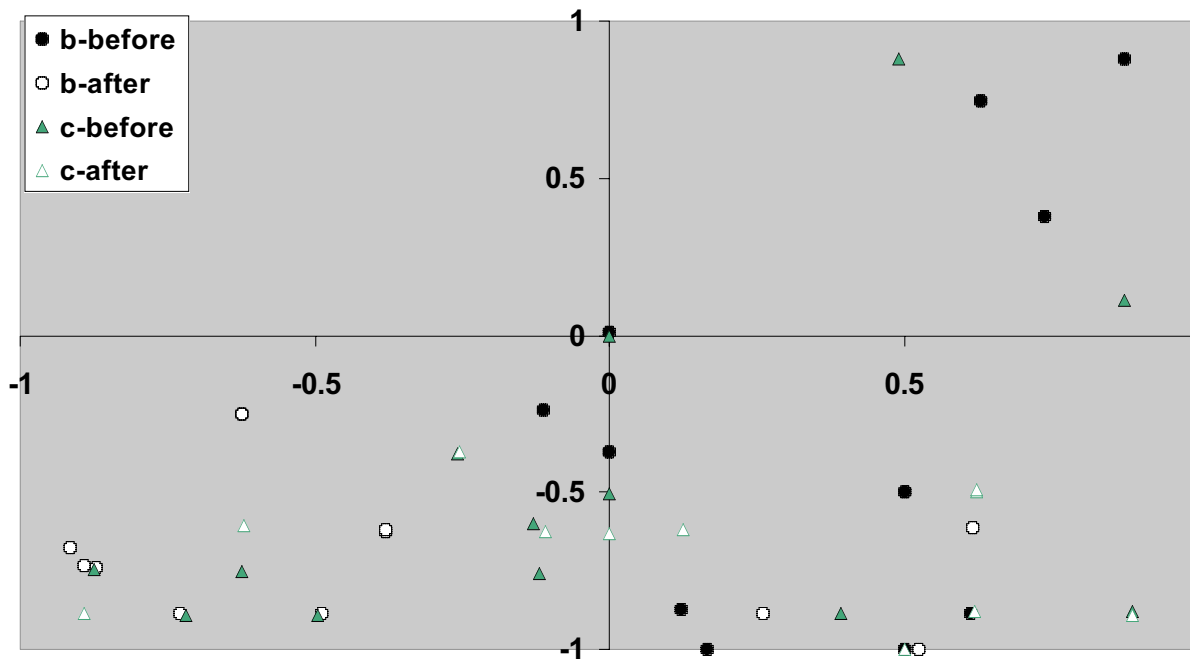


(0, 45, 0, -45)s SAMPLES



Microcrack Trend

Kohonen Map



CONCLUSIONS

Thermography has been shown to be capable of detecting clustered porosity and shows promise for quantifying general porosity level

Resonance ultrasound has been shown capable of detecting the presence of microcracking

The ability to detect microcracking with resonance ultrasound is dependent upon the number of cracks present

FUTURE WORK

Validate thermographic porosity level assessment

Quantify microcrack detection