CURE MONITORING OF CARBON FIBER COMPOSITES FOR MANUFACTURING

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SPE Thermoset TOPCON Conference, May 9-10, 2023

PRECISION CURE MEASUREMENT SOLUTIONS FOR R&D, QA/QC AND MANUFACTURING

https://lambient.com **Stop guessing.**

CARBON FIBER (CF) COMPOSITES MARKET

- 2021 GLOBAL MARKET WAS $18.4 BILLION

- MARKET EXPECTED TO GROW AT COMPOUNDED 6% ANNUAL RATE BY 2030

Source: Global Market Insights' Carbon Fibre Composites Market report released July 2022.

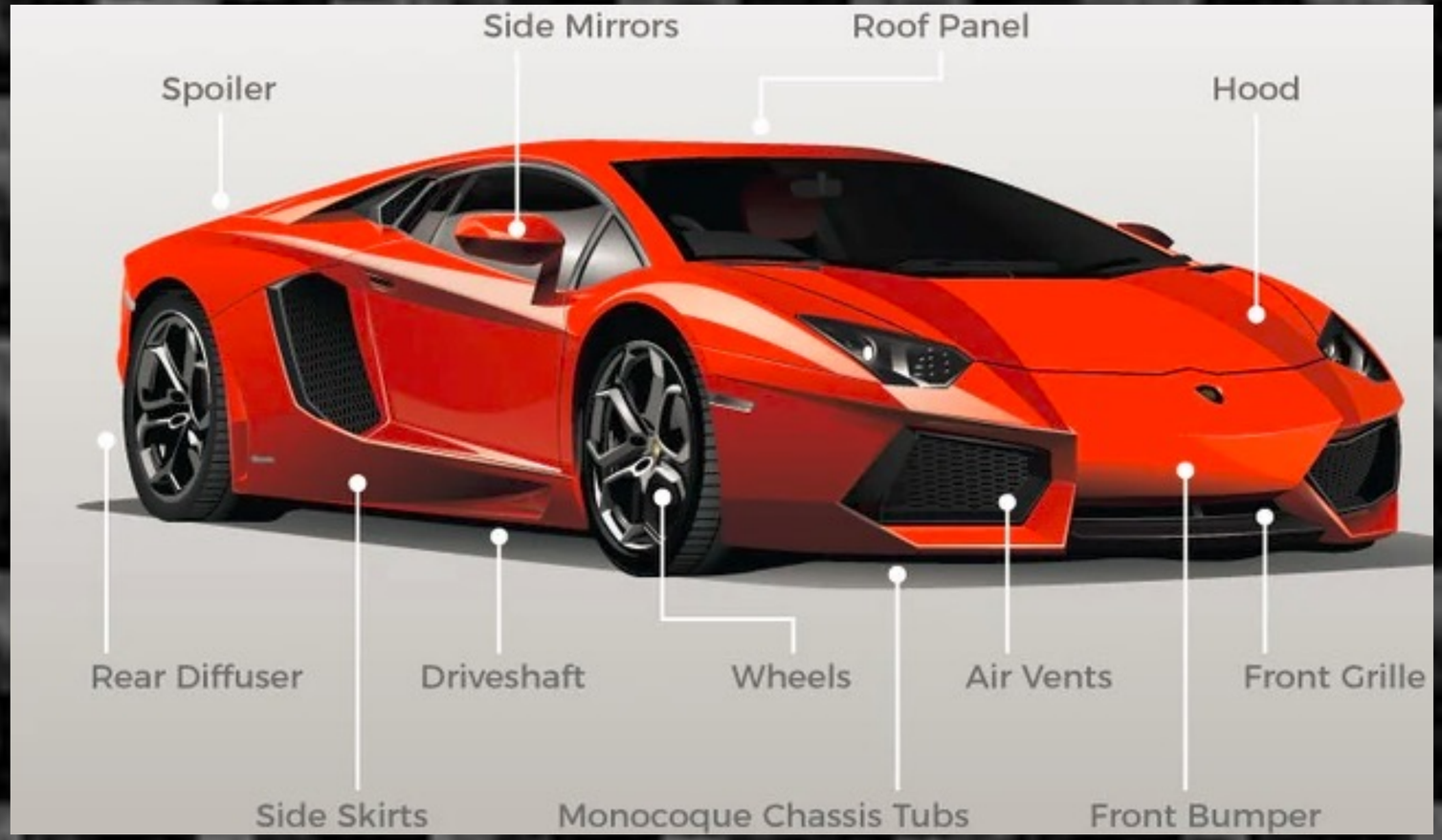
CARBON FIBER (CF) COMPOSITES MARKET

- AEROSPACE AND DEFENSE ESTIMATED TO BE 60% OF MARKET BY 2030
- WIND TURBINE 7% OF MARKET BY 2030
- AUTOMOTIVE 6.5% OF MARKET BY 2030

Source: Global Market Insights' Carbon Fibre Composites Market report released July 2022.

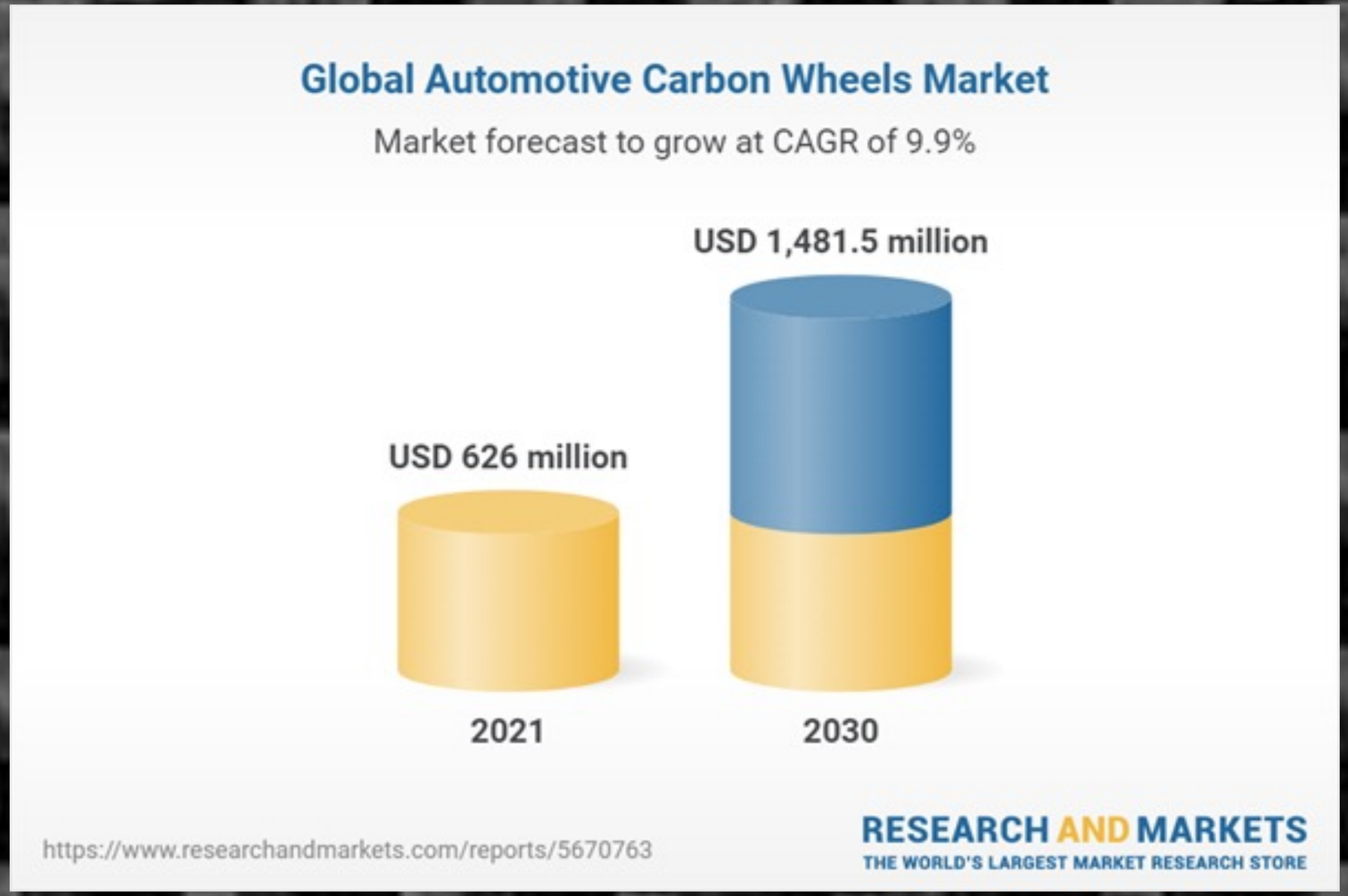
"Automotive manufacturers are actively investing in R&D to develop advanced materials that can be used in high-volume production vehicles."

Source: Global Market Insights' Carbon Fibre Composites Market report released July 2022.

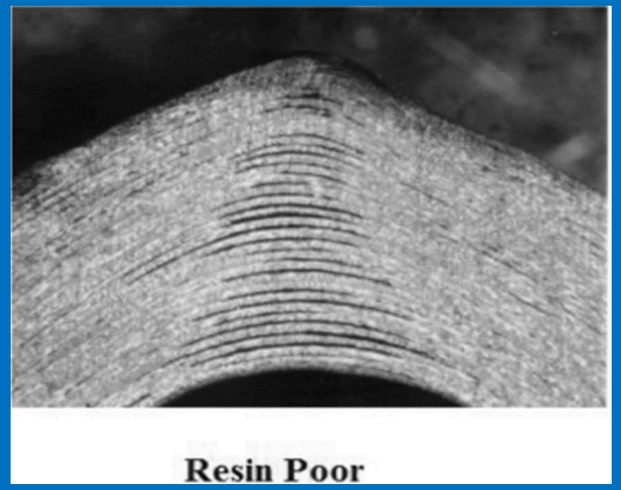


Ref: CarbonFiberGear.com

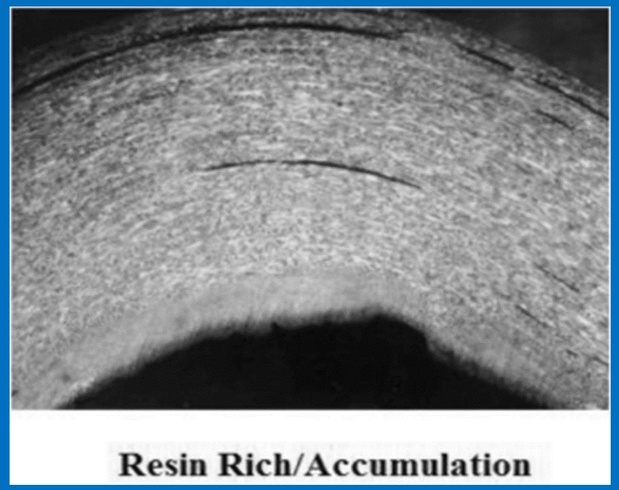
THE GROWING MARKET FOR CARBON FIBER WHEELS



WHY QA/QC CF COMPOSITE CURE BEFORE MANUFACTURING?



Resin Poor



Resin Rich/Accumulation

FIND SMALL PROBLEMS BEFORE THEY BECOME BIG PROBLEMS

QUALIFY INCOMING RAW MATERIAL

- Consistent resin leads to consistent cure

IDENTIFY INCONSISTENT CURE

- Supplier QA/QC may not detect problems
- Variation from batch-to-batch
- Variation within a batch
- Variation from aging during storage

WHY MONITOR CF COMPOSITE CURE DURING MANUFACTURING?

Photo ref: Motor1.com, Koenigsegg carbon fiber wheel

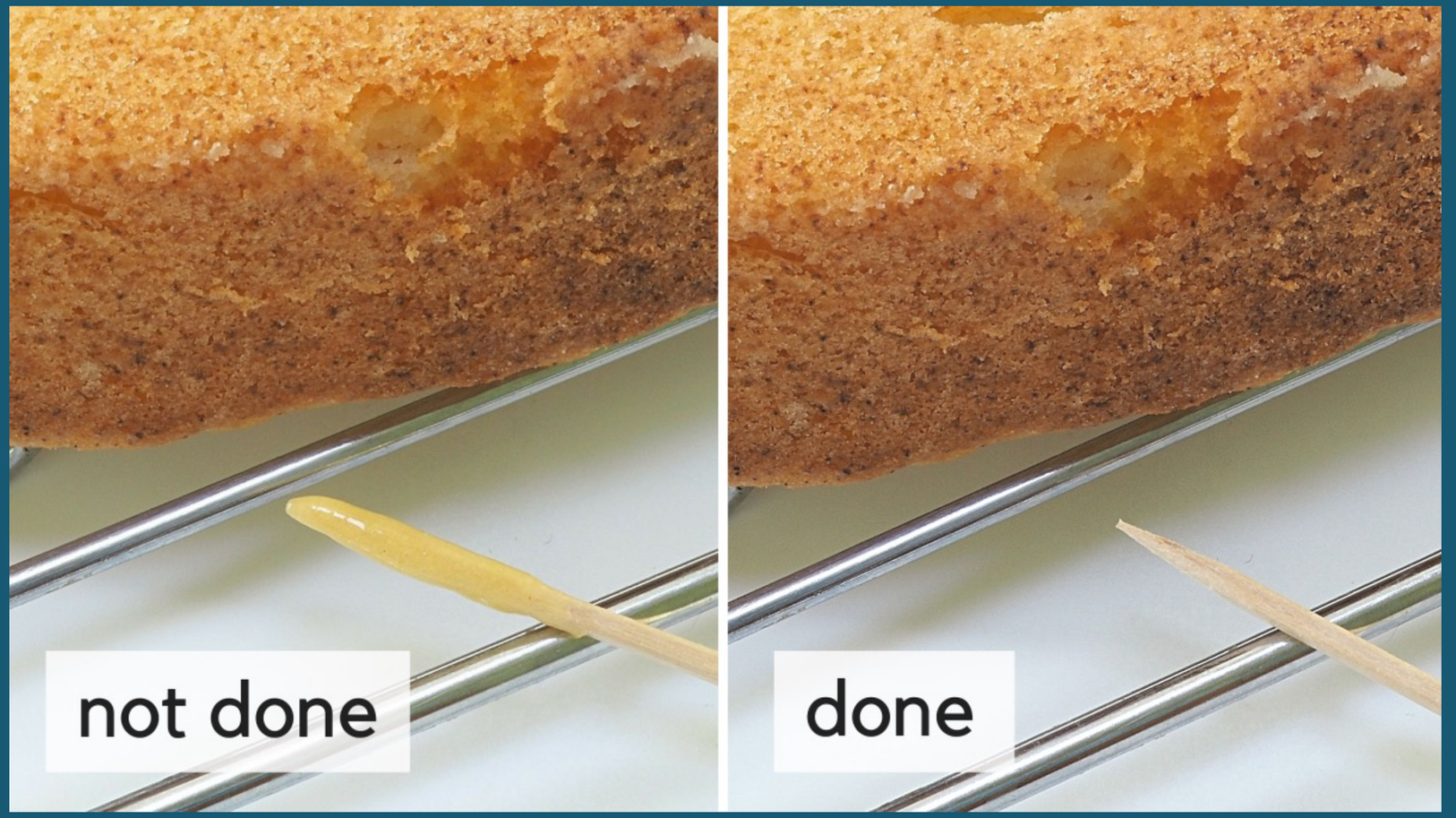
IMPROVE QUALITY:

- Prevent under-curing and premature de-molding
- Prevent over-curing and poor part properties
- Track product uniformity

INCREASE THROUGHPUT:

- Reduce over-conservative mold time

HOW TO MONITOR CF COMPOSITE CURE
(NOT BY TIME AND TEMPERATURE ALONE)



DIELECTRIC CURE MONITORING

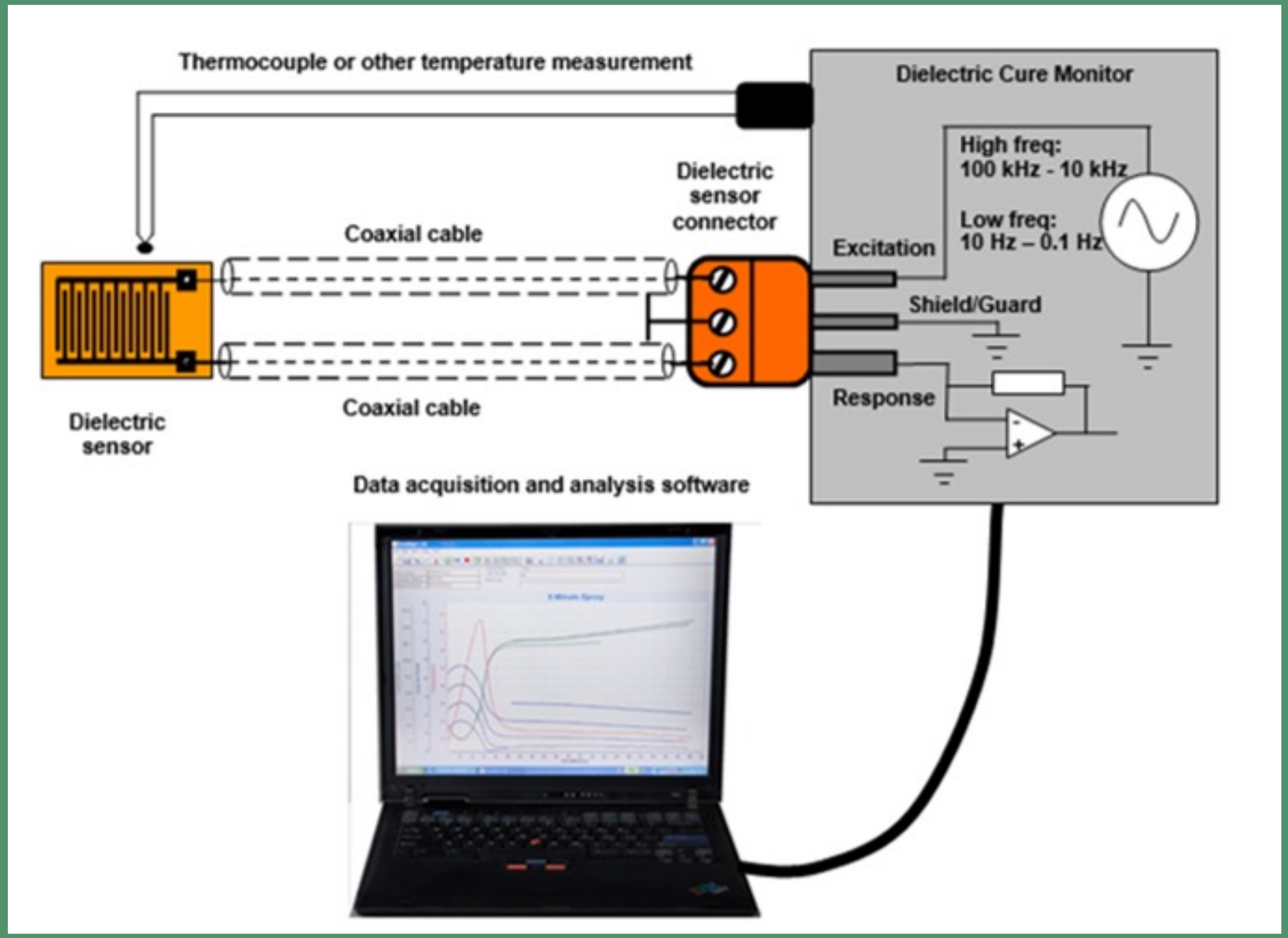
a.k.a. DIELECTRIC ANALYSIS (DEA)

- The only mature test method to measure cure in R&D, QA/QC and manufacturing
- Measures with sensors in-situ and in real-time
- Measures resin material state directly
- Measures resin ion viscosity (electrical resistivity)
- Complements conventional lab tests (DSC, DMA, etc.)

Ion viscosity correlates with cure state

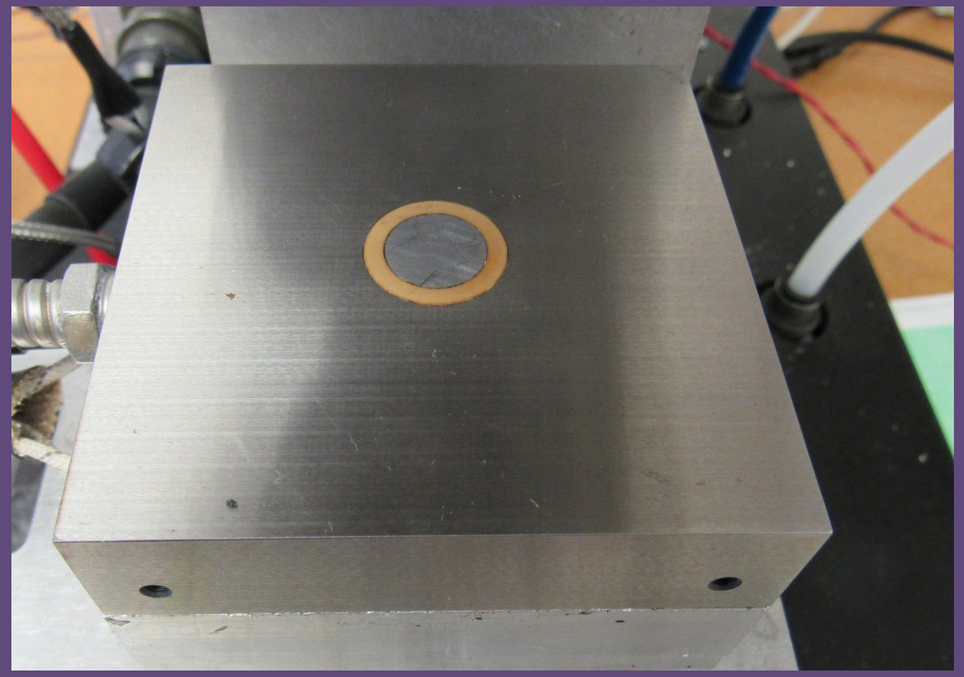
Disposable dielectric sensor

ESSENTIAL ELEMENTS OF A DEA SYSTEM



- Dielectric sensor
- Temperature sensor
- Cabling
- Instrument
- Computer / software

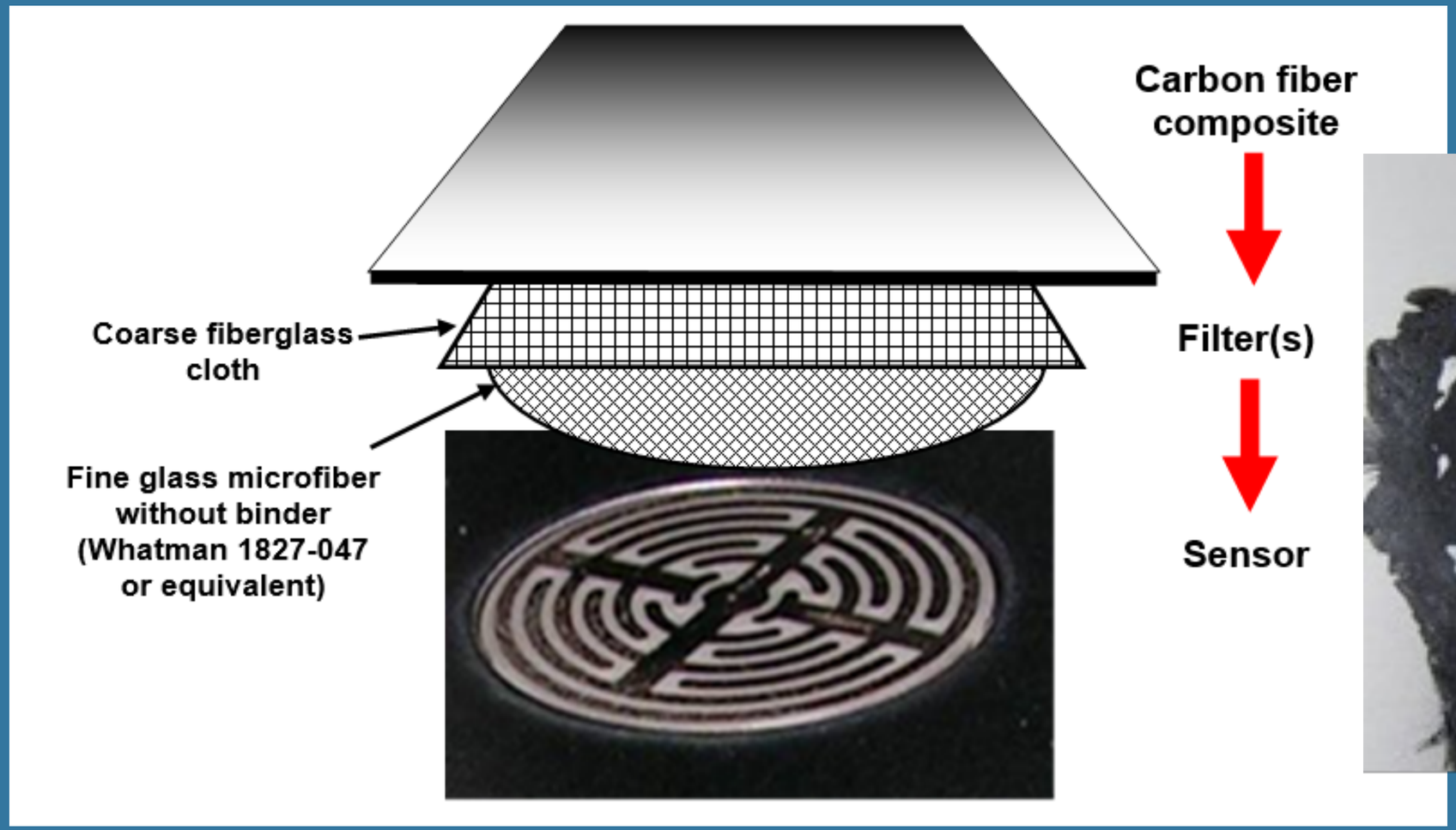
REUSABLE DIELECTRIC SENSORS FOR QA/QC AND MANUFACTURING



Reusable Unitrode sensor for bulk measurements (single electrode)

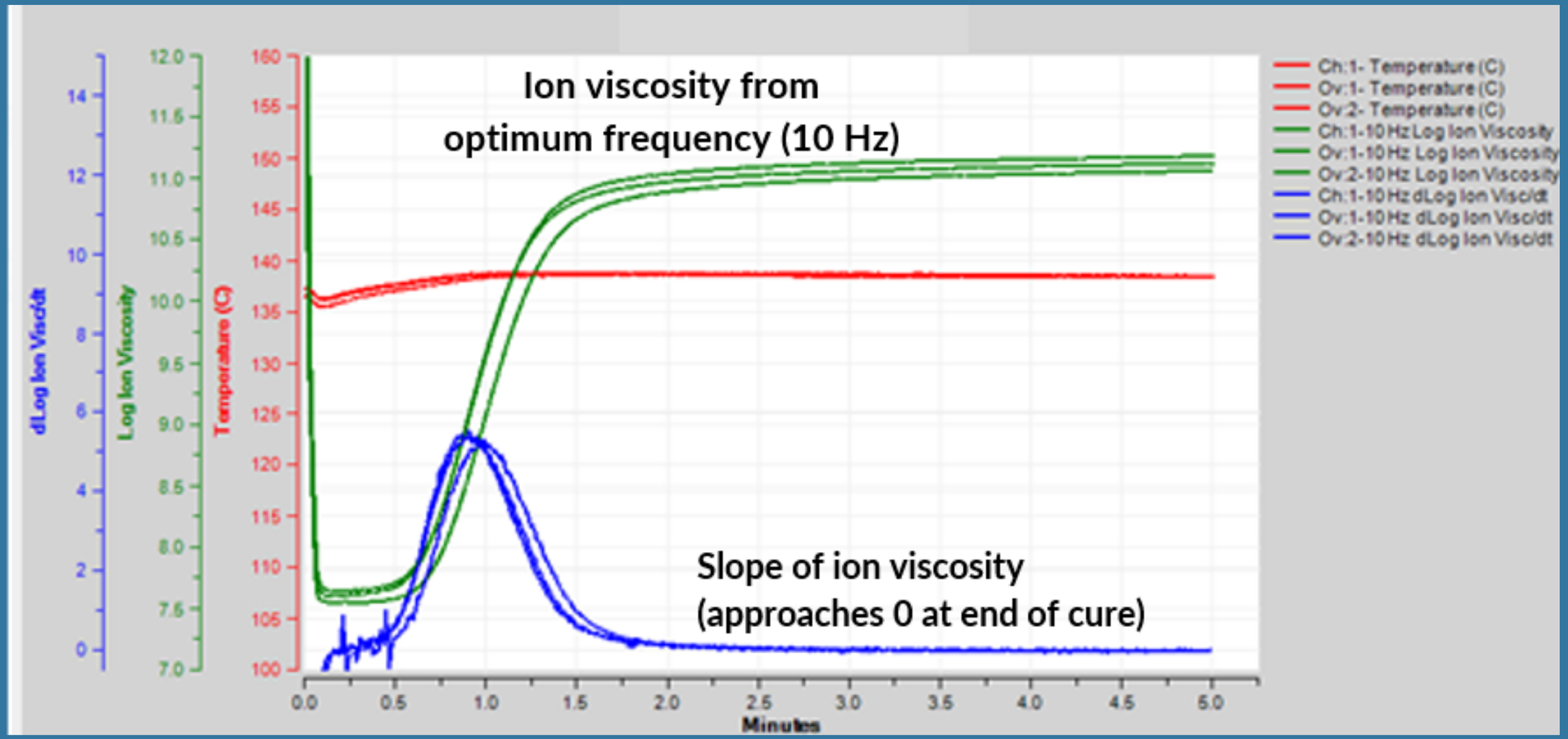
Reusable Ceramicomb sensor for surface measurements (interdigitated electrodes)

BUT CARBON FIBERS SHORT CIRCUIT SENSORS



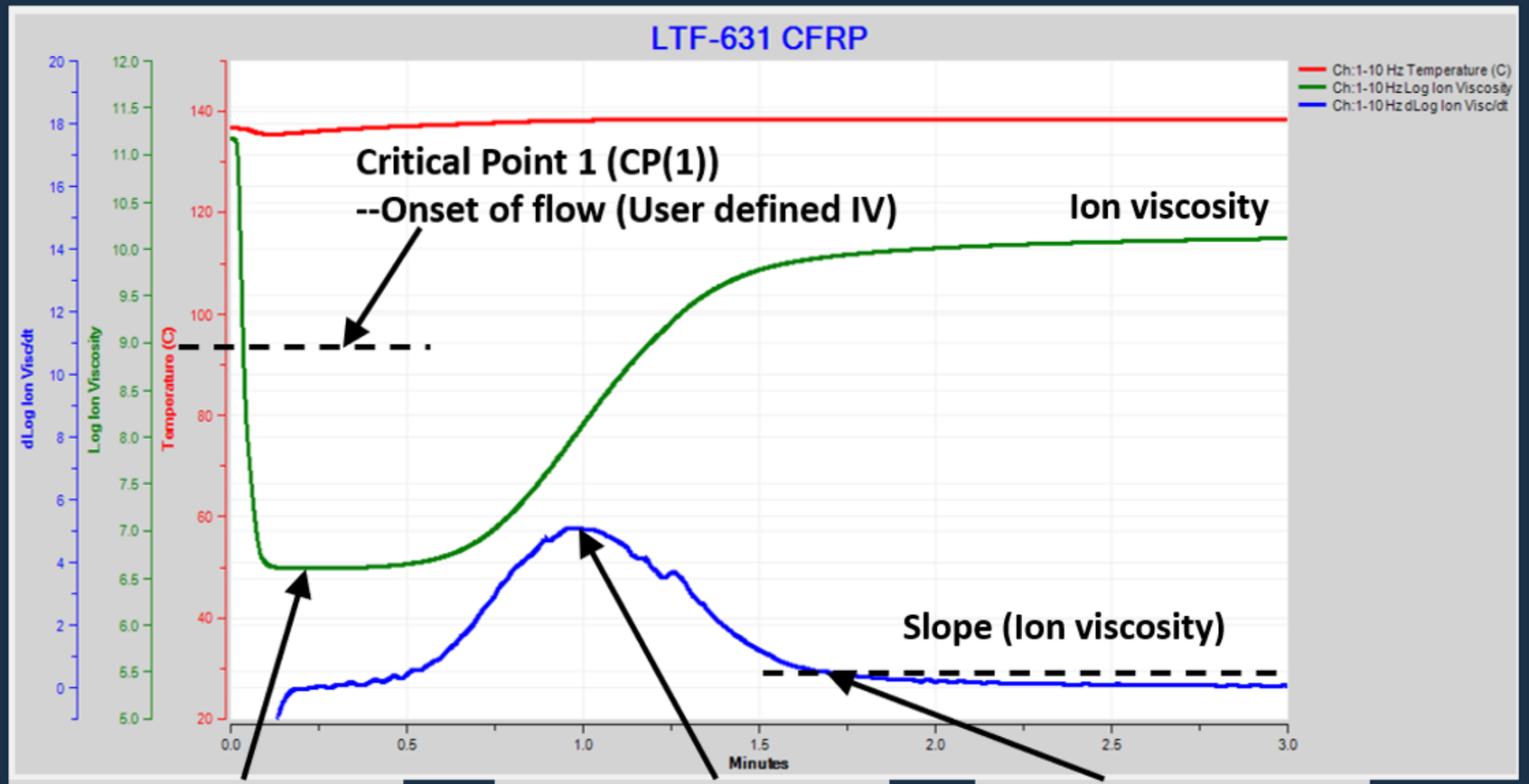
USE FILTERS TO PASS RESIN AND BLOCK FIBERS

QA/QC: CF SHEET MOLDING COMPOUND



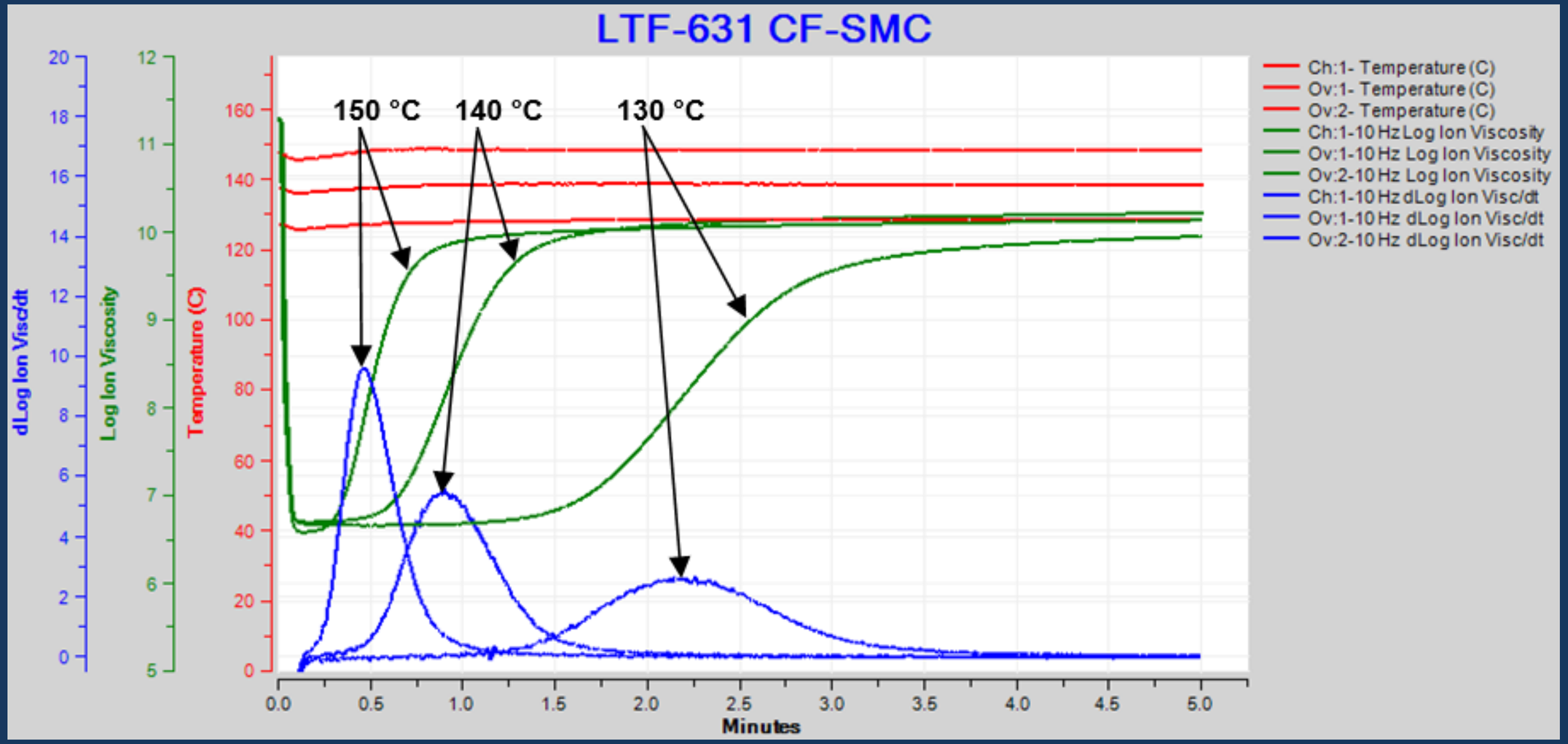
Overlay of three consecutive tests with filtered Ceramicomb

CRITICAL POINTS CHARACTERIZE CURE



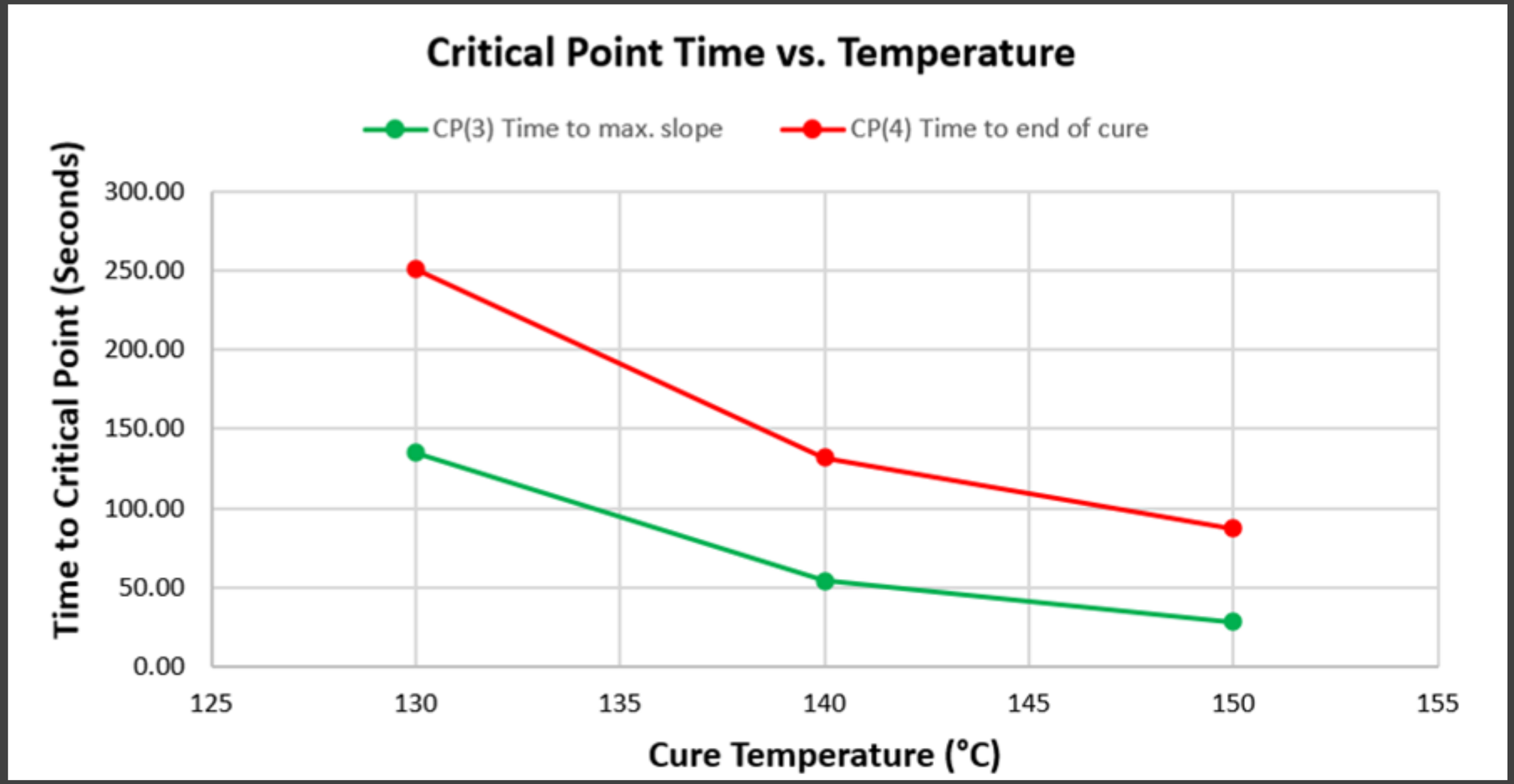
- Ion viscosity correlates with mechanical viscosity before gelation
- Ion viscosity correlates with modulus after gelation
- Change of ion viscosity with time (slope) approaches zero at end of cure
- User defines optimum slope for end of cure

TEMPERATURE AFFECTS CF-SMC CURE



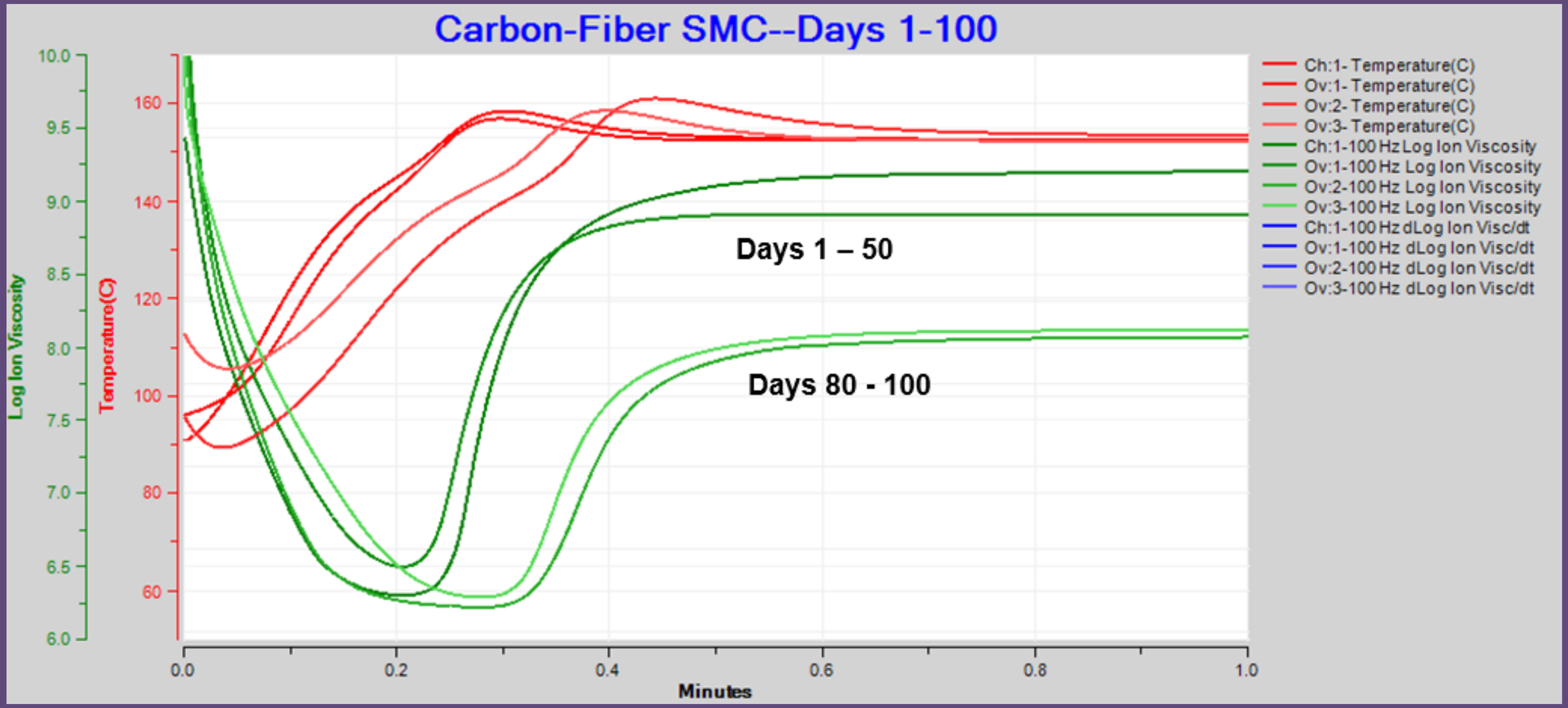
HIGHER TEMPERATURE – FASTER CURE

TEMPERATURE AFFECTS CF-SMC CURE



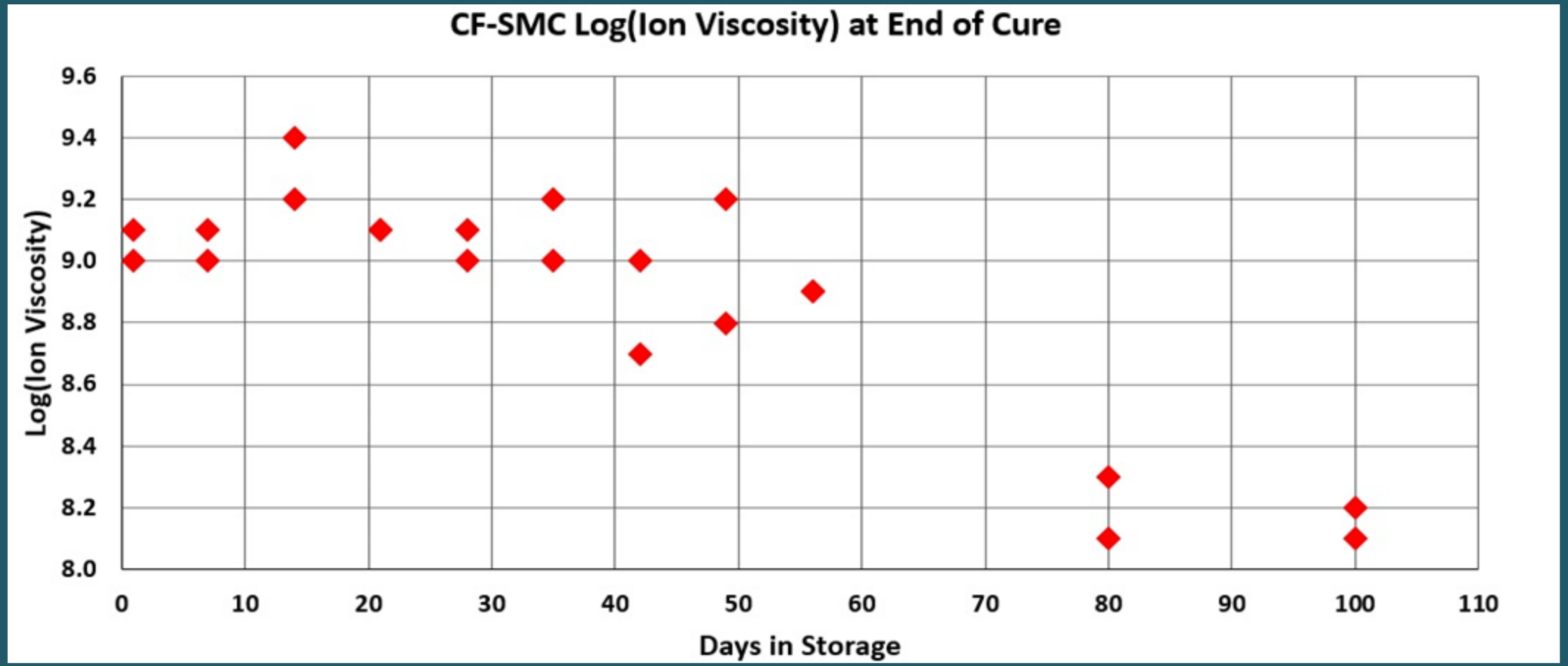
HIGHER TEMPERATURE – FASTER CURE

QA/QC: AGING OF CF-SMC



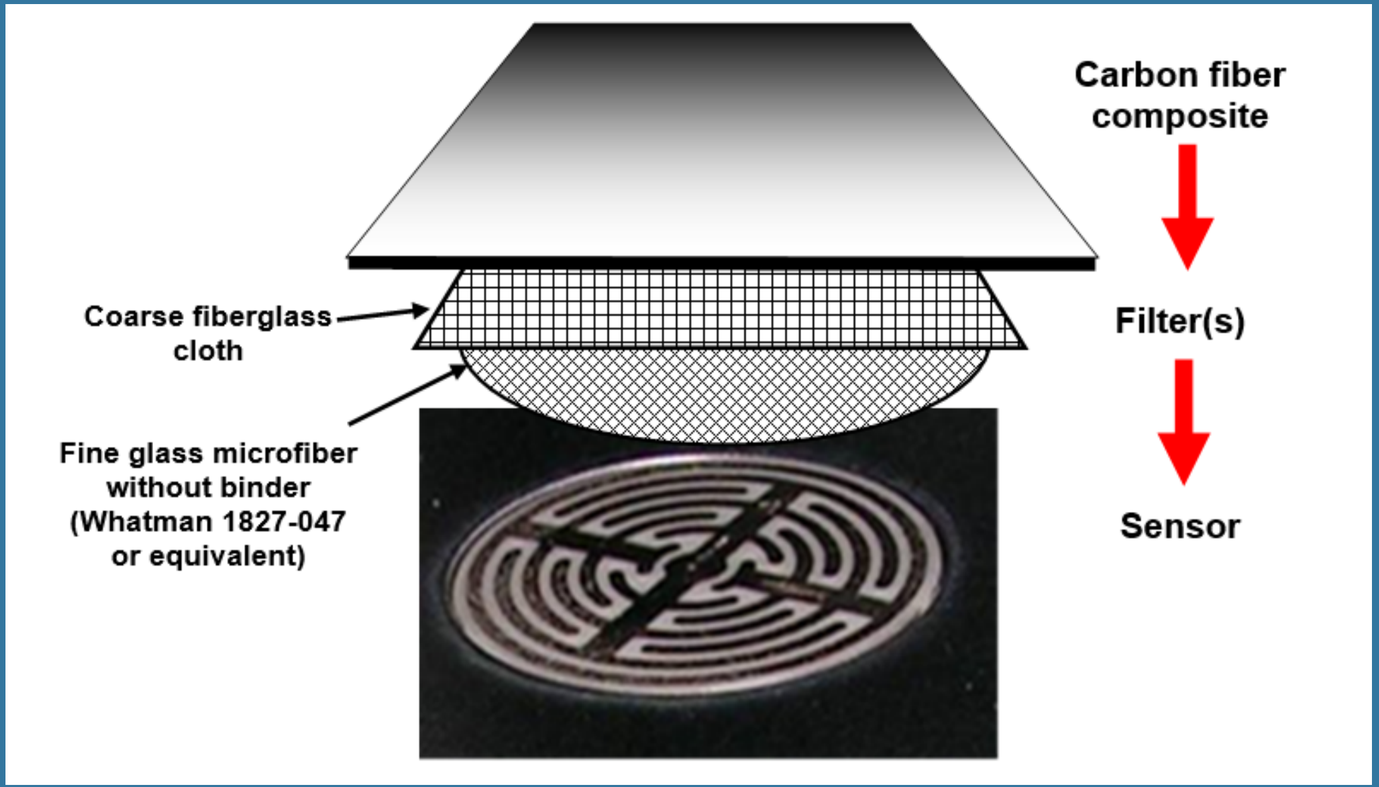
LOSS OF STYRENE: LESS STYRENE – LESS CURE

QA/QC: AGING OF CF-SMC



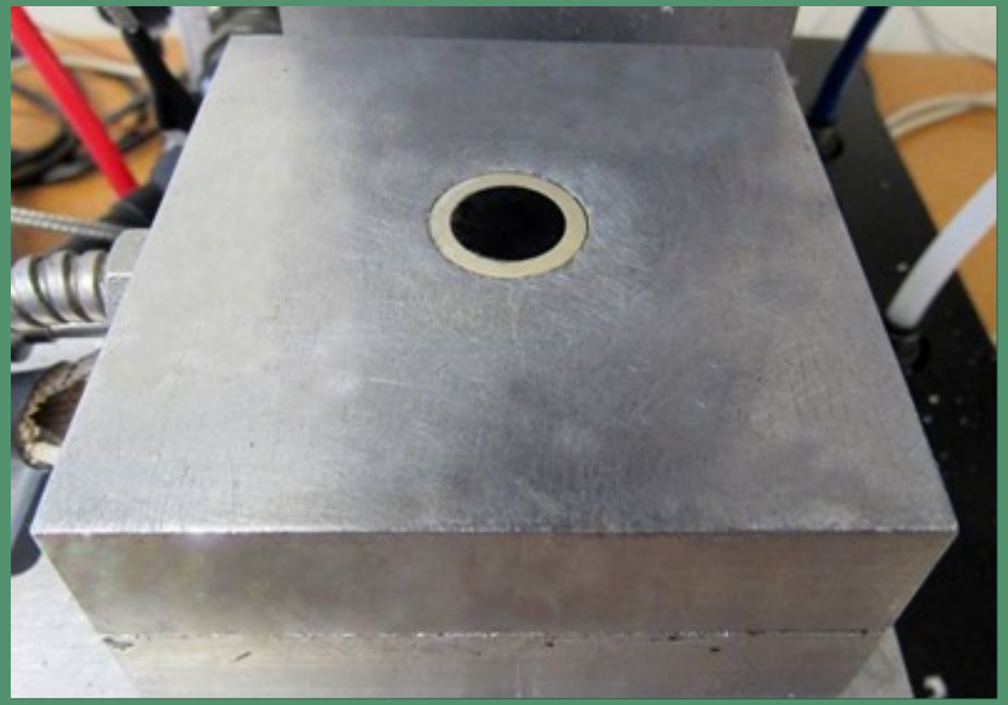
LOSS OF STYRENE: LESS STYRENE – LESS CURE

FILTERS WORK WELL FOR QA/QC BUT NOT FOR MANUFACTURING

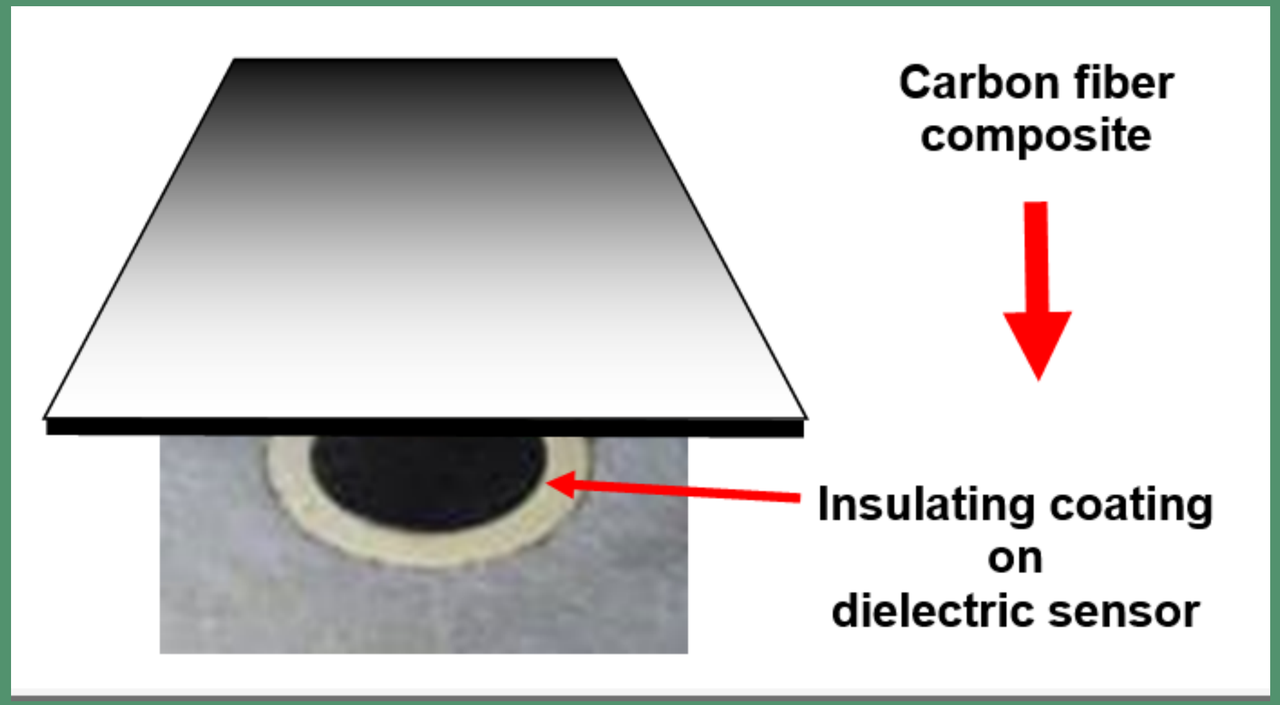


FILTERS MUST BE MANUALLY REPLACED FOR EACH TEST ---TOO TIME CONSUMING FOR RAPID PRODUCTION

CARBON+SENSOR FOR MANUFACTURING



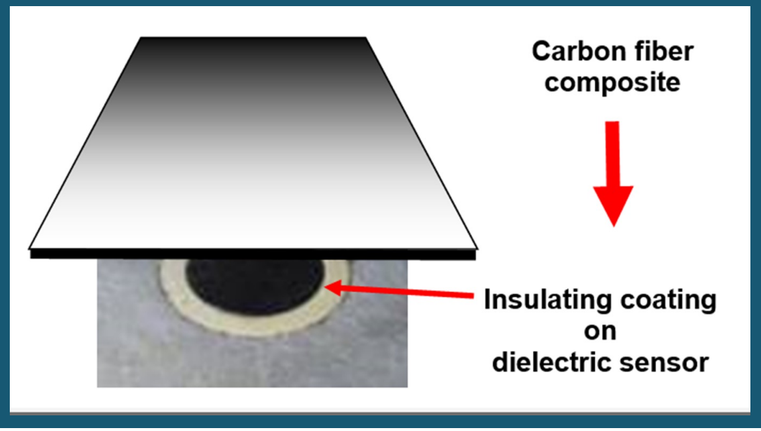
Carbon+Unitrode-1” sensor

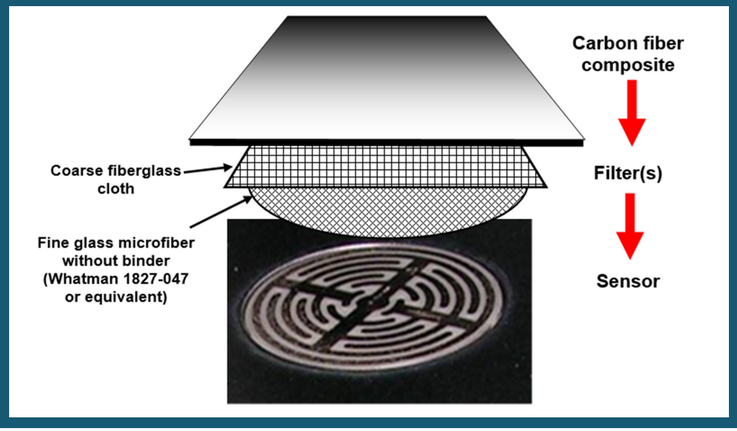


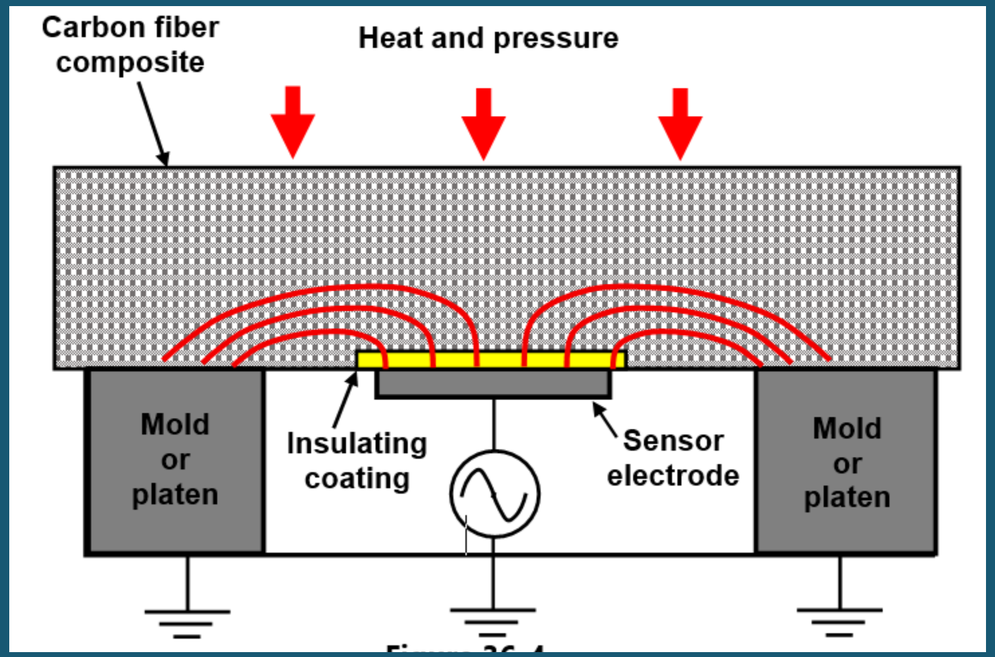
COATING ALLOWS CONTACT WITHOUT FILTERS

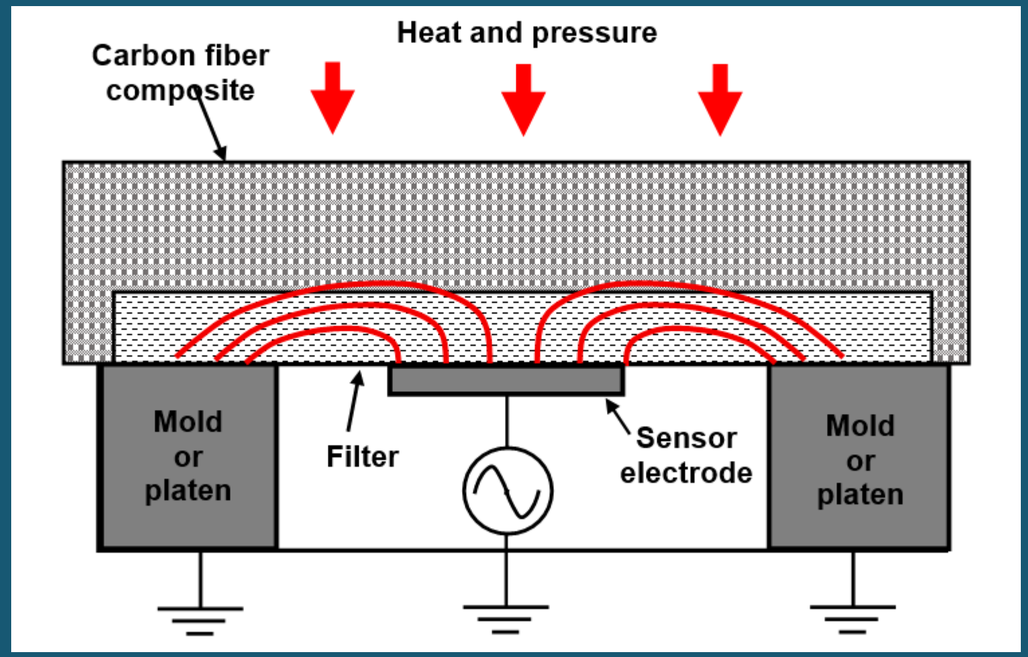
12 MM DIAMETER ELECTRODE

DIRECT CONTACT vs. FILTERED SENSORS





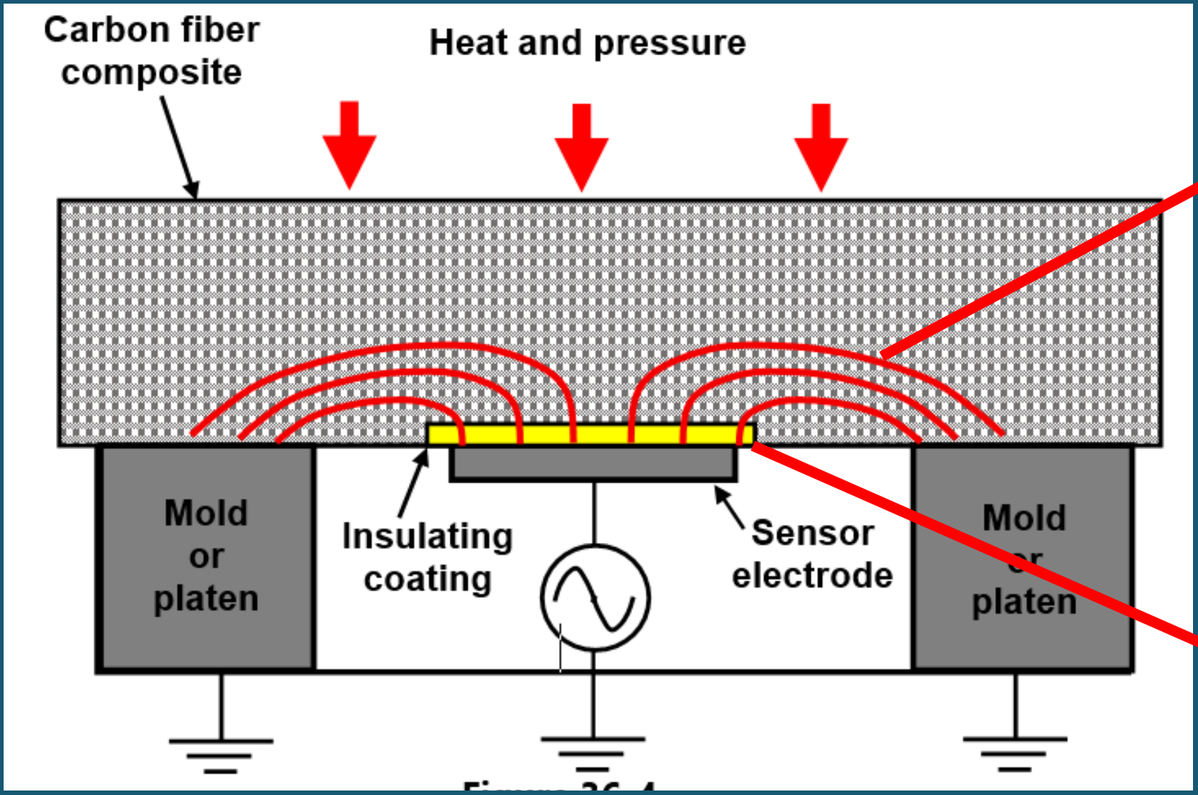




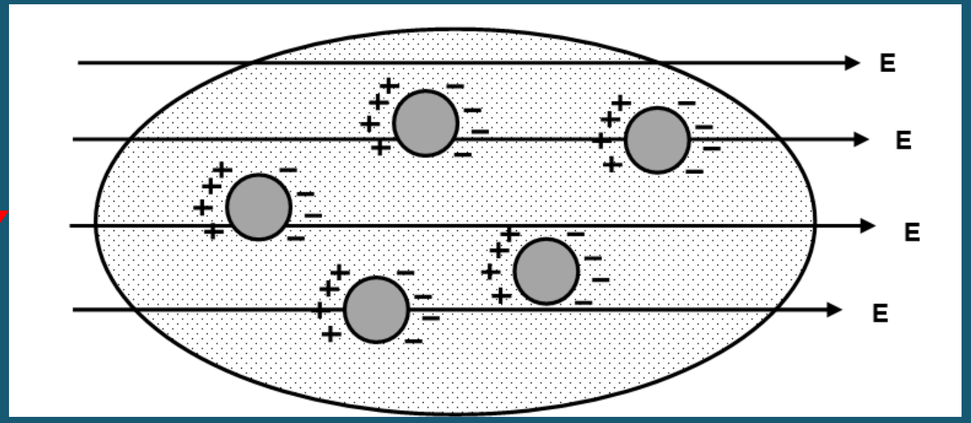
Measures resin cure in conductive carbon matrix

Measures resin cure in non-conductive filter

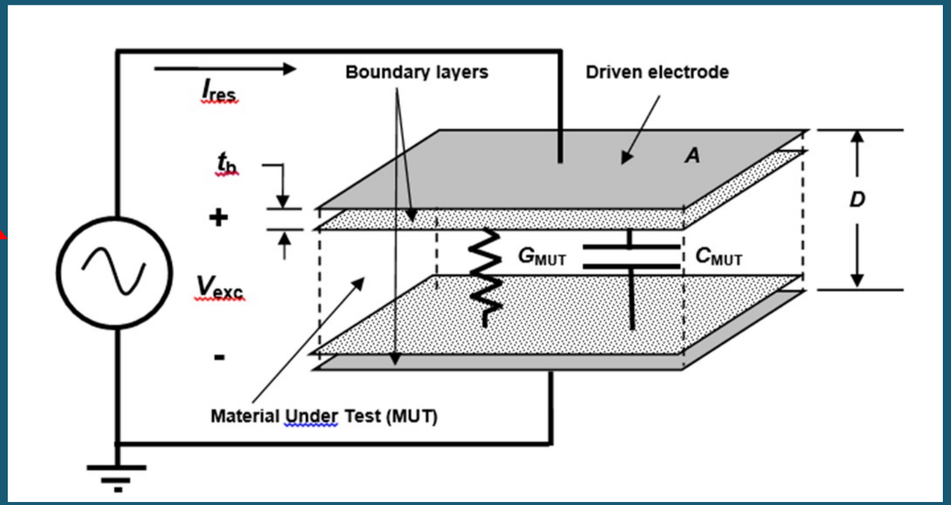
PHENOMENA CAUSED BY DIRECT CONTACT CAN DISTORT DATA



Schematic of Carbon+Unitrode-1” sensor in press platen

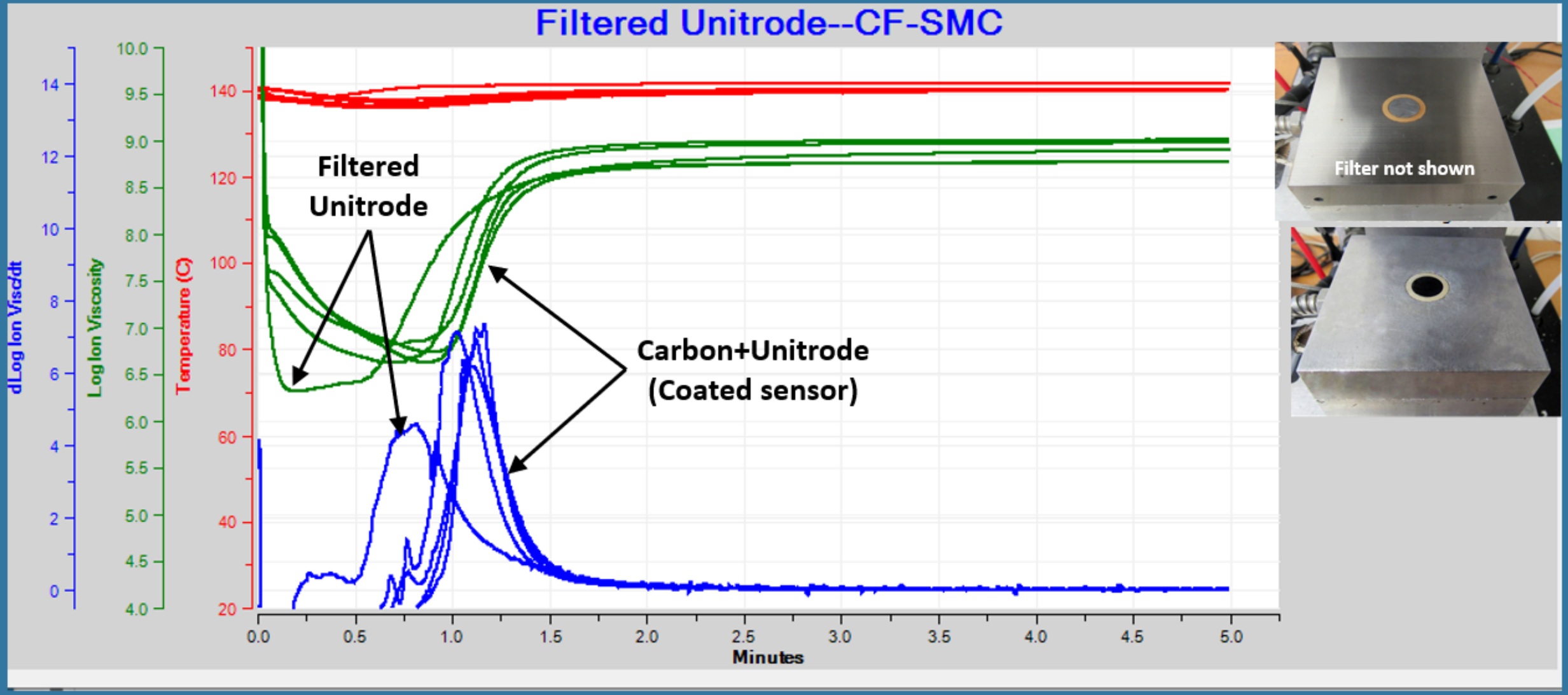


Maxwell-Wagner-Sillars polarization in inhomogeneous materials

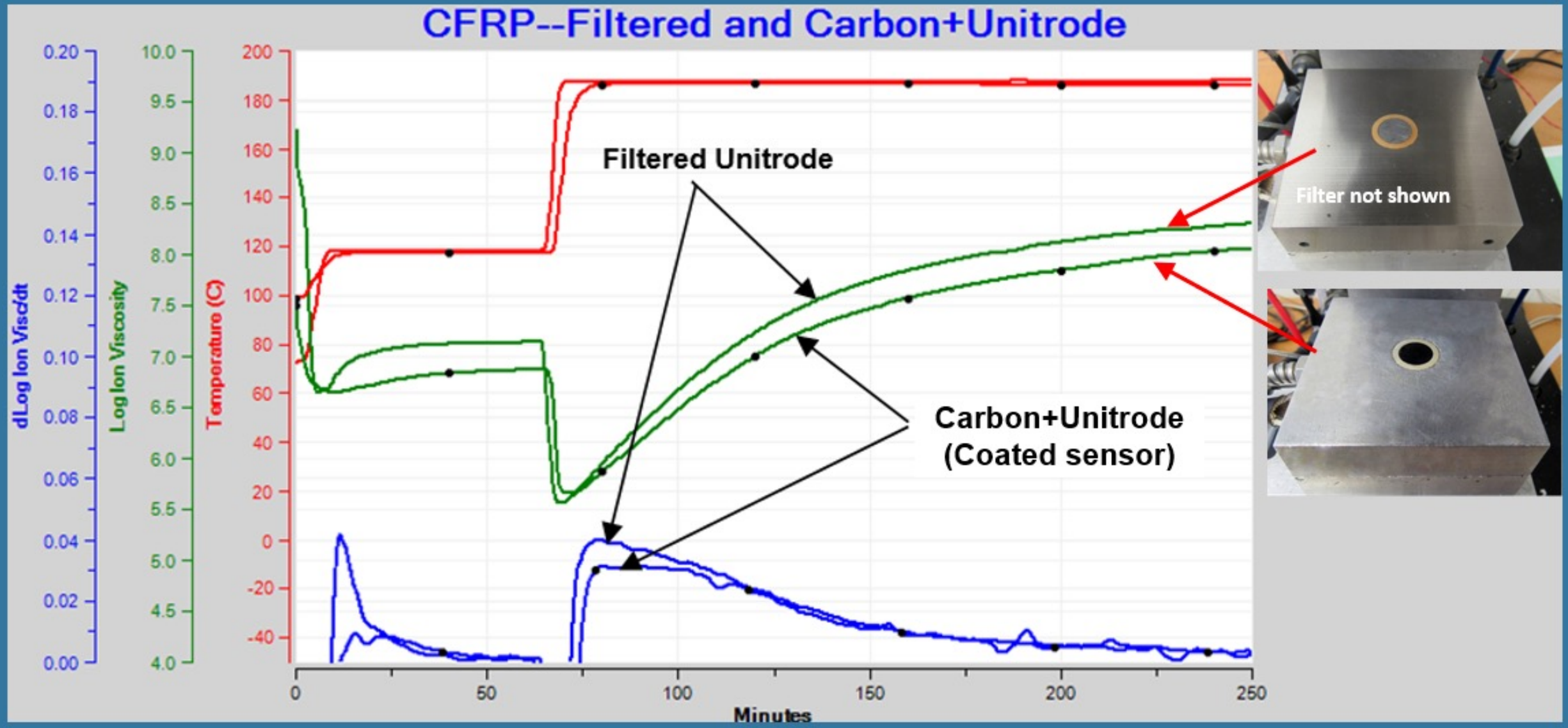


Boundary layer polarization on insulating coating

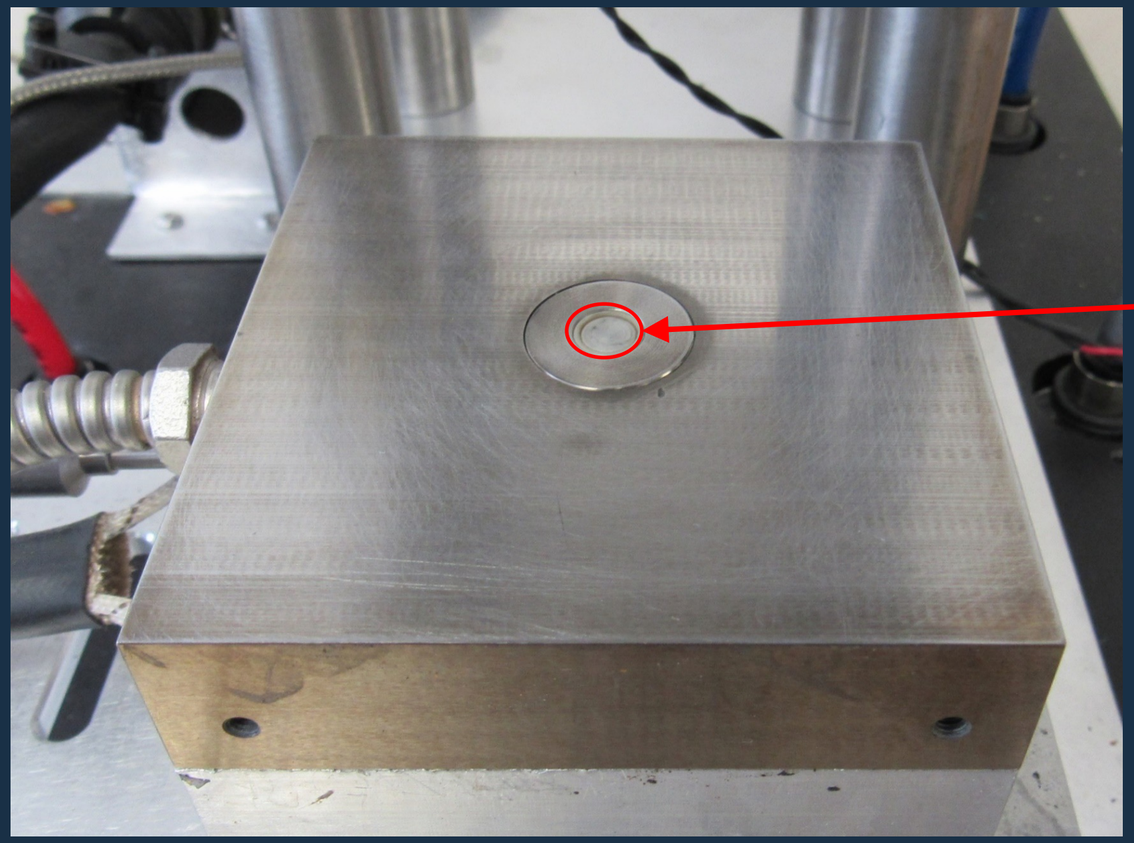
COMPARISON: CF-SMC



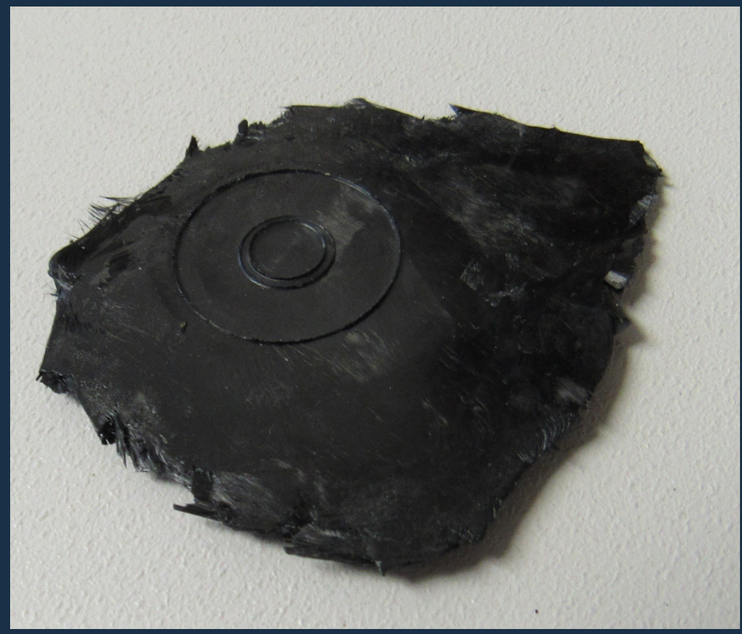
COMPARISON: EPOXY-CF PREPREG



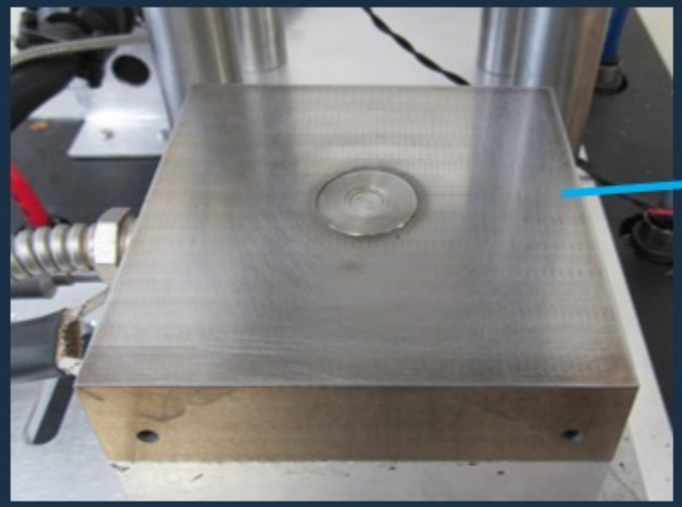
CARBON+MINITRODE FOR MANUFACTURING

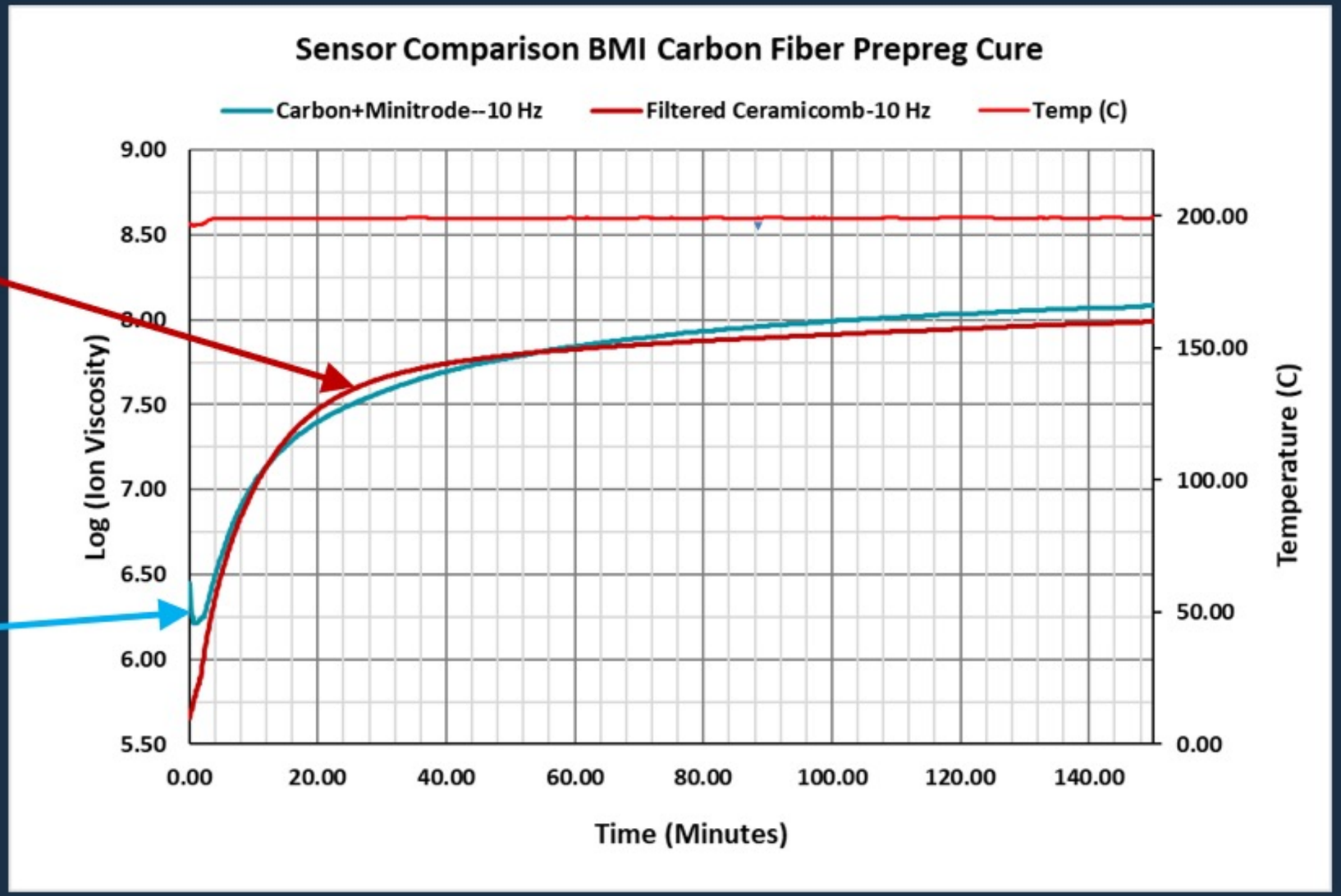


- Smaller configuration for tight spaces
- 6 mm diameter electrode



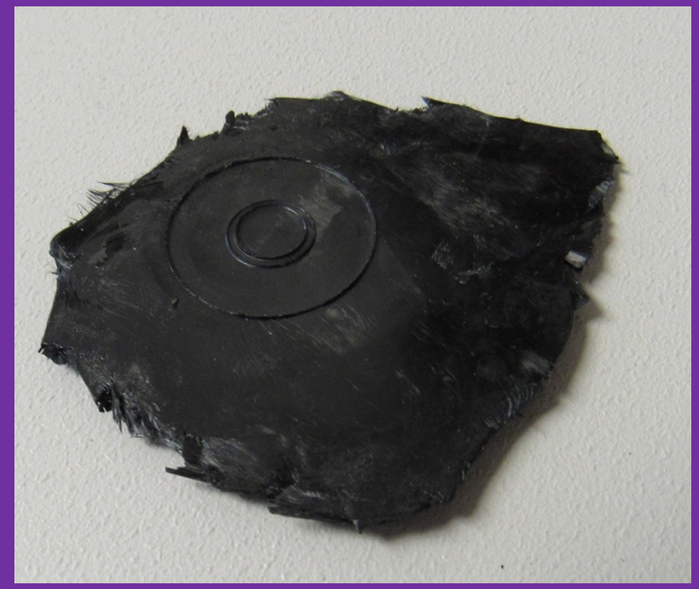
COMPARISON: BMI CARBON FIBER PREPREG





DIRECT CONTACT CARBON+SENSORS

- MEASUREMENTS CORRELATE WITH CURE
- FOR MANUFACTURING w/CF COMPOSITES
  - IV CURVES CONSISTENT FOR A GIVEN CF-COMPOSITE
  - IV DISTORTION DEPENDS ON CF-COMPOSITE TYPE
    - RESIN FORMULATION? RESIN VISCOSITY?
    - FLOW THROUGH CARBON FIBER MATRIX?
    - RESIN-CARBON FIBER RATIO?



QUESTIONS?

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