CURE MONITORING OF CARBON FIBER COMPOSITES FOR MANUFACTURING

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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

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

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

THE GROWING MARKET FOR CARBON FIBER WHEELS

Global Automotive Carbon Wheels Market

Market forecast to grow at CAGR of 9.9%

USD 626 million
USD 1,481.5 million

2021
2030

https://www.researchandmarkets.com/reports/5670763
WHY QA/QC CF COMPOSITE CURE BEFORE MANUFACTURING?

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?

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

Photo ref: Motor1.com, Koenigsegg carbon fiber wheel
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
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

Ion viscosity from optimum frequency (10 Hz)

Slope of ion viscosity (approaches 0 at end of cure)

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

LTF-631 CF-SMC

150 °C  140 °C  130 °C

HIGH TEMPERATURE – FASTER CURE
TEMPERATURE AFFECTS CF-SMC CURE

HIGHER TEMPERATURE – FASTER CURE
QA/QC: AGING OF CF-SMC

Carbon-Fiber SMC--Days 1-100

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

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

Filtered Unitrode

Carbon+Unitrode (Coated sensor)
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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