EB Cure Monitoring
A Brief Overview of the Issues and the Possibilities

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Curing and Why Monitor It

Curing

- **Process by which a liquid thermosetting pre-polymer is turned into a rigid solid**
- **Chemical reactions which elongate and cross-link the polymer molecules**

Why Do We Wish to Monitor Curing

- **Process control and optimization**
- **Part quality assurance**

Cure Variations Affect Part Quality

- Ambient and Elevated Temperature Mechanical Properties
- Dimensional Stability
- Damage Tolerance
- Environmental Resistance (moisture, acids, etc.)
- Residual Stresses

Typical Thermal Cure Monitoring

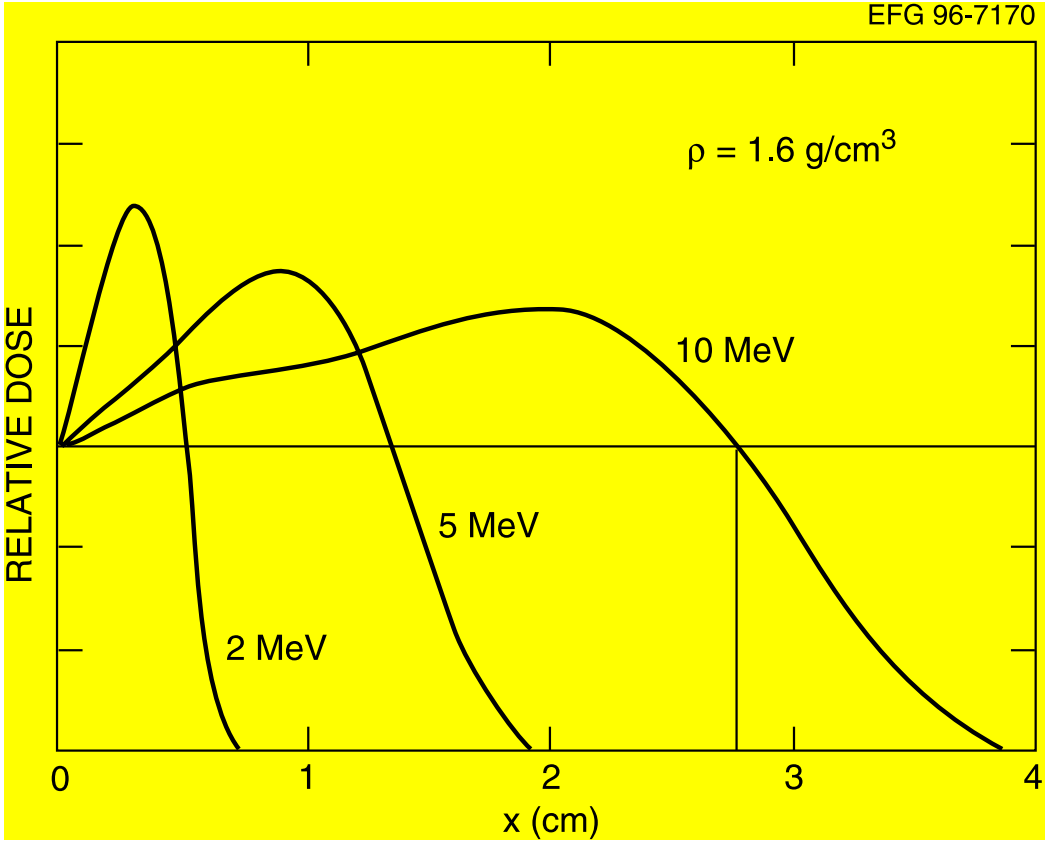
- **Physical Variables Almost Always Tracked Include**
  - **Temperature**
  - **Pressure**
- **Other Variables**
  - **Flow and part fill extremely important in resin infiltration processes**
  - **Other techniques employed primarily in part development or small production**
- **Witness Samples Used as Verification**
  - **Not useful for mid-process corrections**

Radiation vs Thermal Curing

- Pressure Rarely Used in Open Mold EB Curing - Adequate Consolidation a Concern
- Curing Chamber Temperature of Limited Value
- Part Temperatures More Valuable as Exotherm Warning than Cure Indicator
  - Interior temperature from embedded sensors
  - Surface temperature varies from internal values
- Dose Measurements for Radiation Curing Analogous to Temperature for Thermal Cure

Dosimetry

- **Limited Dose Range Per Device**
- **Uneven Dose Deposition Profile Throughout Part**



Other Key Radiation Curing Issues

- Beam Scan Programming Critical to Dose Deposition Uniformity
- Parts Frequently Long Distances From Operator
- Rotating Parts Add Complexity
- Instrumentation Needs Shielding From Radiation and Protection From Ozone
- Electrical/electronic Signals May Be Subject to Noise/interference From Process

Other Monitoring Techniques

Multiple Standard and Non-standard Measurements Based on the Following:

- **Dielectrics**
- **Ultrasonics**
- **Fiber Optics**
- **Spectroscopic**

Dielectric Measurements

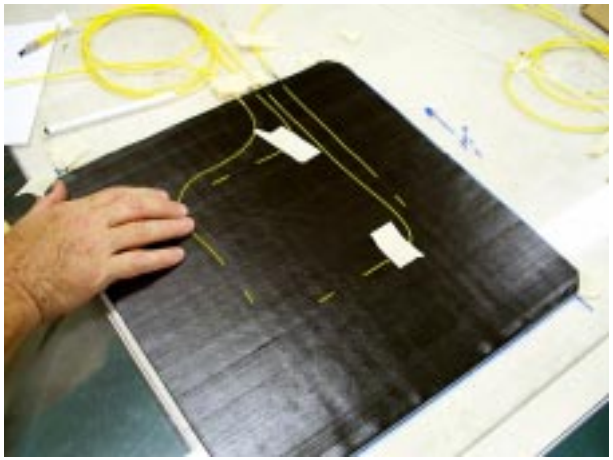
- Commercial, Off-the-shelf, Multiple Channel Systems Available
- Provide Indication of Flow State, Gel Point, and End of Cure Point
- Reusable Sensors for Surface Detection, but Embedding May Cause Part Defects
- End of Cure Sensitivity Is Debatable

Ultrasonic Systems

- Variety of Techniques Available
- Temperature/reliability Limitations Being Overcome
- Useful As Indicator of Several Quality Issues Such As Flaws, Porosity, Density, Etc Throughout the Part
- Can Be Used in Non-contact Applications

Fiber Optics

- Can Provide Wide Variety of Information Including Temperature, Pressure, Strain, Moisture, Etc.
- Sensor Length Is Essentially Unlimited and Cost Relatively Small
- Small Size Makes Embedding in Parts Without Defects Practical
- Connections May Be Difficult and Small Fibers Are Not Very Durable at Interfaces



Spectroscopic Methods

- Most Direct Measure of Cure Via Chemical State Evaluation
- Variety of Methods and Techniques Including Capability for Measurement at Interphase Region
- May Be Combined With Fiber Optics for Remote Measurements
- May Be Used in Non-contact Applications

Summary

- Temperature, Primary Variable in Thermal Curing, Yields Little Data on Radiation Cure
- Dosimetry Is Currently the Most Cost-effective Technique for Simple Parts, but Has Limitations
- Other Techniques May Offer Greater Advantages When Fully Demonstrated for This Application
- Ideal Technique Would Cost-effectively Allow Full Thickness Characterization Without Part Invasion