Oak Ridge Centers for Manufacturing Technology

Tooling Materials Assessment for Electron Beam Curing of Composites

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EB Curing of Composites Workshop

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Objectives

- Identify Decision Factors
- Processing Options
- Penetration Thickness
- Temperature Rise
- Radiation Stability
- Examples
- Conclusions

Basic Premise

- **In Most Cases, Conventional Fabrication Tooling Concepts (Typically Metal) Can Also Be Used for Electron Beam Curing; However, These Materials May NOT Be Optimum in Terms of:**
  - **Costs**
  - **Weight**
  - **Temperature Rise (with Energy Absorption)**
  - **Ability to Pass Energy Through (in a closed mold)**
- **In Many Cases, Electron Beam Curing Opens the Door to Alternate Tooling Materials and More Cost Effective Solutions**

Design Factors For Tooling

- Fabrication Process Itself
- Dimensional Stability/Achievable Tolerances
- Mold Fabrication Process (Number Of Steps)
- Maintenance, Transportability, Handling
- Repair
- Alterability
- Venting/Removal Of Trapped Air And Volatiles
- Need For Resin Flow
- Desired/Required Thermal Expansion

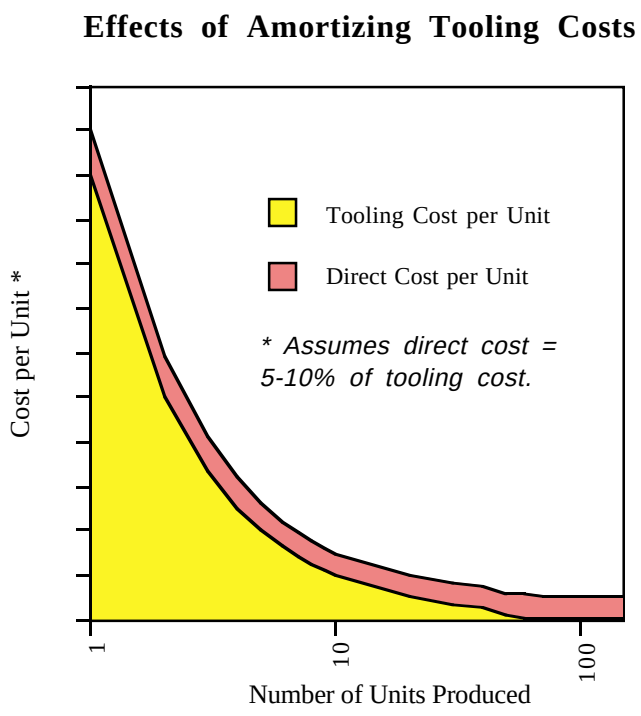
- Part Release
- Wear/Durability/Toughness
- Weight
- Thermal Mass
- Thermal Conductivity
- Required Part Curing Pressure
- Temperature Level And Distribution
- Cooling
- Undercuts, Hardware, Inserts
- Surface Finish
- Ease Of Mold Duplication

Composite Processing Options for EB Curing

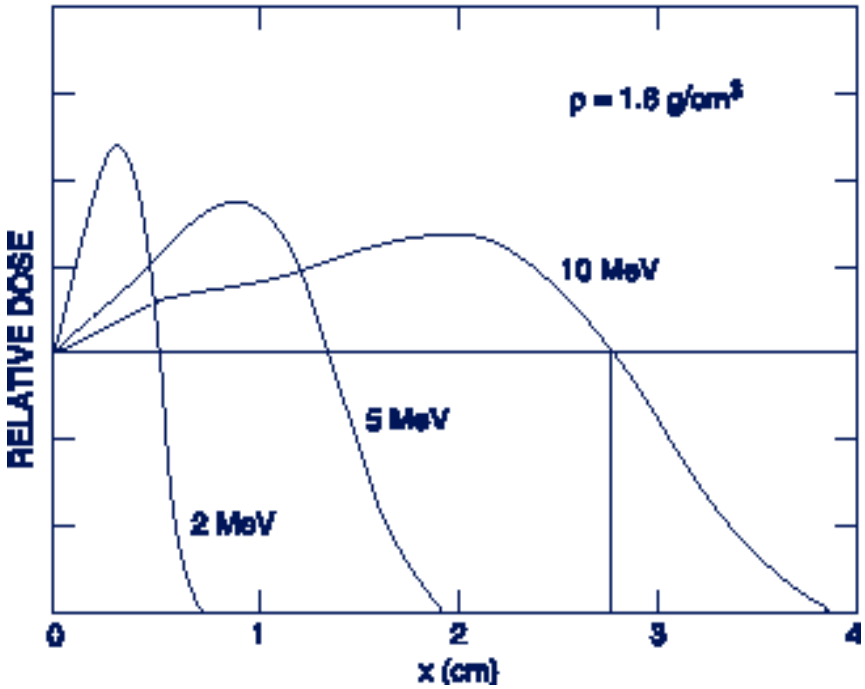
- **Applicable for a Number of Processes**
  - Hand layup
  - RTM/VARTM
  - Filament winding
  - Tape layup
  - Fiber placement
  - Pultrusion
  - Adhesives
- **Cure Possibilities**
  - Total cure on tool after processing
  - Partial cure on tool, complete free standing
  - Cure in-situ

Tooling Costs vs Production Quantity

- **Large Scale Production**
  - Durability (RAM) primary driver
  - Cost somewhat easy to amortize
- **Small Production Numbers**
  - Durability very important
  - Cost is significant factor
- **Prototype Development**
  - Tooling durability is not the driver due to frequent changes/modifications make
  - Tooling cost may make or break entire project



Effects of Beam Power and Energy



- **Electron Penetration Through a Target is a Function of:**
  - **Energy of the Electron Beam**
  - **Density of the Target Material**
- **Material Throughput is a Function of Beam Power**
  - **Dose rate α power**

Penetration Depth

Effective beam penetration (providing relatively uniform dosage) can be estimated from the following relationship:

$$Wa = \frac{E}{2.2}$$

where **Wa = material areal weight in g/cm^2, and**

E = beam energy in MeV.

Penetration Thickness/Temperature Rise Examples

Material	Density	Penetration Capability (E=10 MeV)*	Specific Heat	Heat Rise (D=35 kGy)**
	g / cm^3	cm	J / (g x C°)	C°
Aluminum	2.74	1.63	0.97	36
Steel	7.68	0.58	0.46	76
Epoxy	1.24	3.59	1.84	19
PVC Foam	0.24	18.56	0.97	36
Polyurethane Foam	0.77	5.79	1.67	21
Phenolic	1.55	2.87	1.30	27
Carbon fiber/epoxy	1.59	2.80	1.13	31
Glass fiber/epoxy	2.17	2.05	0.63	56

* Assumes equation E = 2.2 x Wa, where Wa is in g/cm^2
** Assumes adiabatic process ΔT = Dose / Specific Heat

Temperature Rise

Maximum temperature rise due to radiation exposure can be estimated as follows:

$$T = \frac{D}{Cp}$$

where **T = temperature rise in C°**

D = exposure dosage in kGy, and

Cp = material specific heat in J/(g • C°).

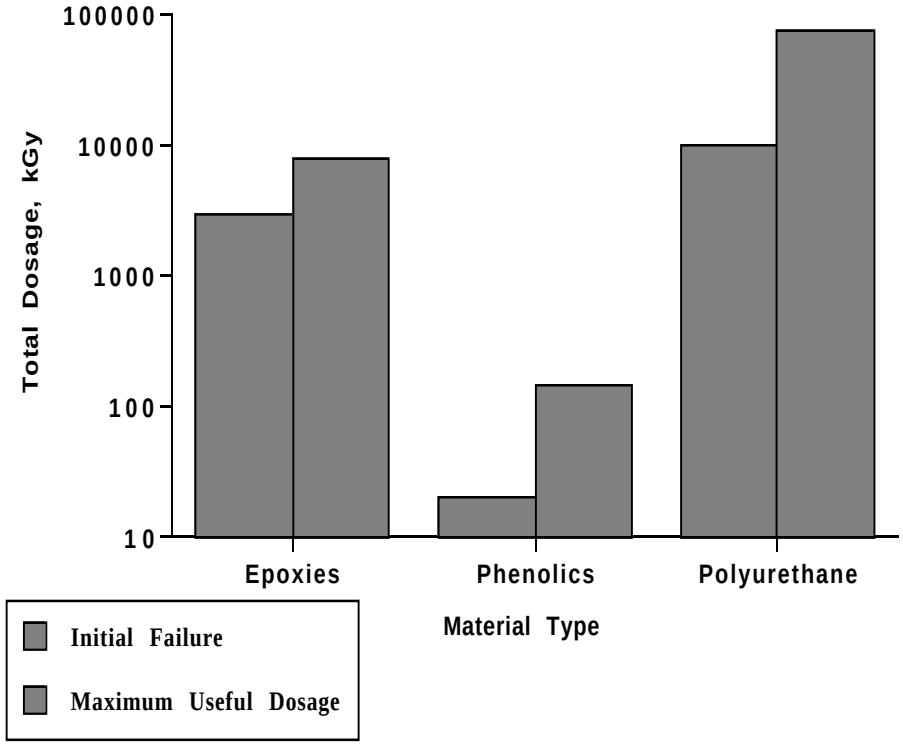
Examples of Materials Being Screened/Evaluated

- Organic Matrix Composites
- Polymers
- Foams
- Castable Ceramics
- Plasters
- Wax
- Wood
- Paper
- Combinations of Above

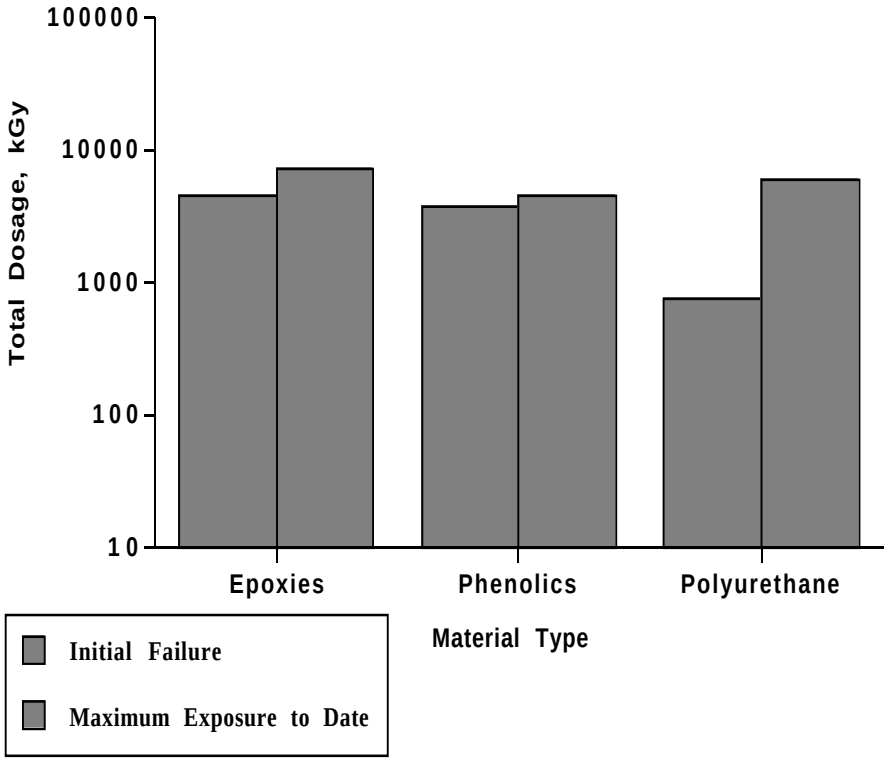
Radiation Endurance

Published Data

Van de Voorde and Restat



Current Test Data



Bagging/Bleeders/Release Films

Preliminary studies indicate most products work to some degree, although:

- Some materials slightly inhibit curing on part surface
  - Surface inhibition primarily due to “proprietary” mold releases rather than bagging materials
  - Catalog materials compatibility ratings are not necessarily relevant to EB curing
  - Because most EB curing is at lower temperatures than thermal curing, cheaper materials may be adequate
- A few materials do not have adequate radiation stability for most curing
  - Fluorocarbons

Mold Releases

- **Compatibility Involves Interaction of three materials**
  - **Fabricated part materials**
  - **Mold release**
  - **Tool materials**
- **Issues**
  - **Because of Radiation Induced Cross-linking, Catalog materials compatibility ratings are not necessarily relevant to EB curing**
  - **Proprietary nature of formulations makes generalized comparisons difficult**
- **Mixed Results with**
  - **Waxes**
  - **Silicones**
  - **Teflons**

Examples

Includes pictures of some/most of the following:

- **PVC MANDRELS/Thick and Thin Parts**
- **SCRIMP PARTS**
- **PAPER MANDRELS**
- **ABS CYLINDER OVERWRAP**
- **WOOD FORMS/PARTS**
- **LAYUP OF FOAM ONTO SURFACE**
- **WAX FORMS**
- **METTERS**

Conclusions

- Electron Beam Curing Offers Tremendous Opportunities to Use a Variety of Alternate Materials for Tooling
- Biggest Impact in Cost Savings may be Prototypes, Unique Products, and Production of a Few Hundred Units or Less
- Literature is a Good Starting Point for Materials Assessment, but May be Misleading
- Need to Continue Studies of Mold Releases

Acknowledgements

- **Tooling Materials Evaluation**
  - Collaboration with LMTAS
  - Materials vendors
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  - AECL and E-Beam Services
  - Materials
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    - Foam - Divinycell International
  - Molds
    - TPI, Inc. and Metters Industries
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