Electron Beam Curing of Composites

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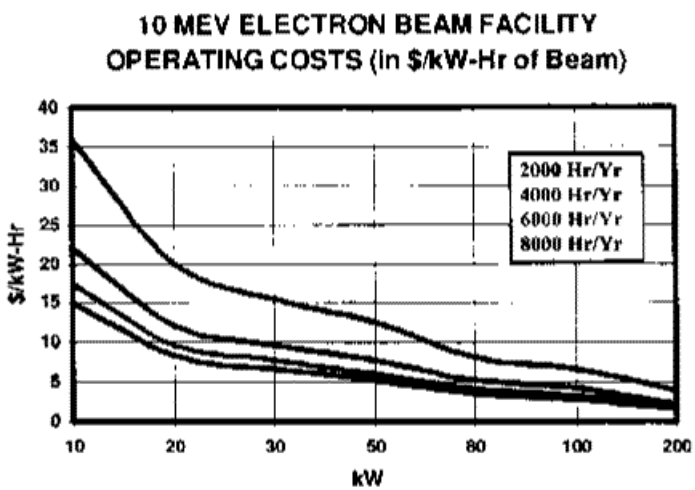
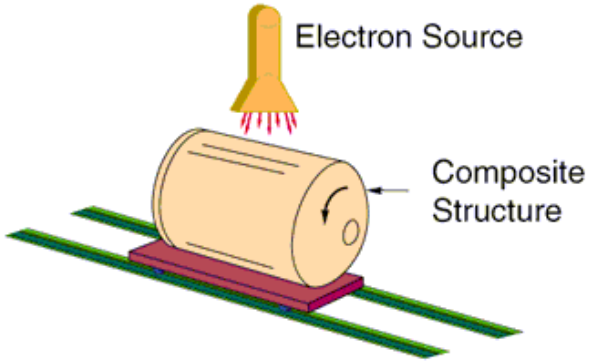
The E-Beam Curing Payoff -

- AFFORDABILITY
  - Short cycle times
  - Part count reduction
- ENABLEMENT
  - Enlarged operational envelope



Electron Beam Curing Of Polymer Matrix Composites

Electron beam curing is a very fast, nonthermal, nonautoclave curing method that uses high-energy, high-power radiation to cure polymer matrix composite parts/structures; therefore, making them more affordable. ORNL is the leader in a national program to advance electron beam curing technology and to standardize its use in the government and private sectors.



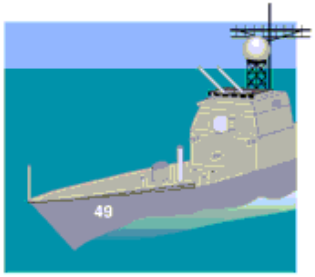
Benefits: Electron Beam Curing vs Thermal Curing

- Nonthermal, nonautoclave curing process
- Significantly reduced cure time (10–1000x)
- Simpler material processing/handling
- Lower cost tooling
- Reduced toxic emissions
- Better part quality/performance
- Lower manufacturing costs

Applications

Space Systems

Marine Systems



Infrastructure

Ground Vehicles

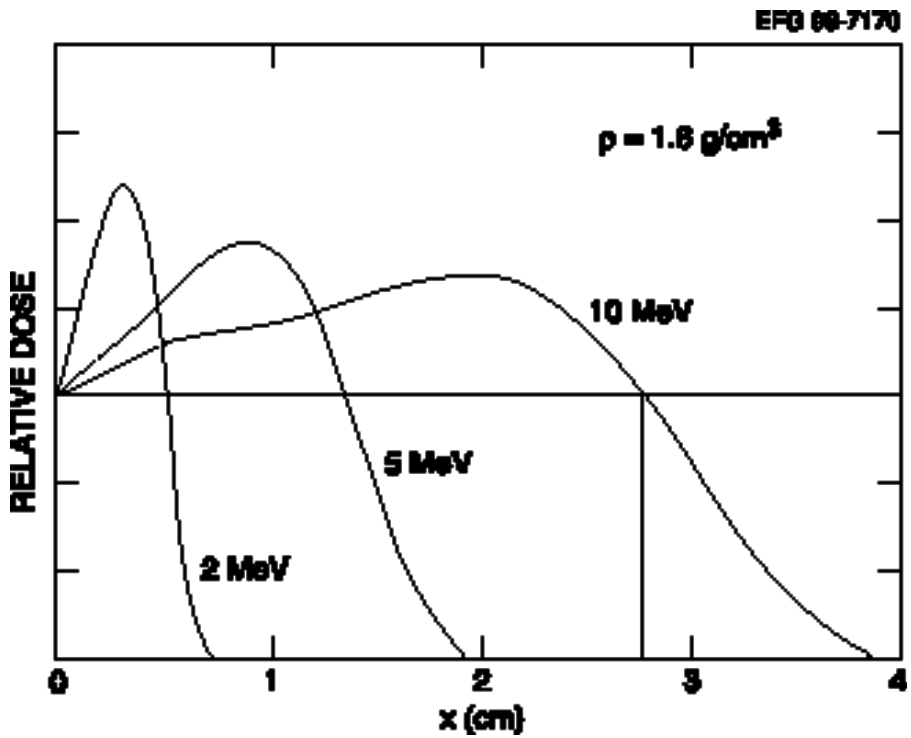
Automotive

Aircraft Systems

Recreational Sports

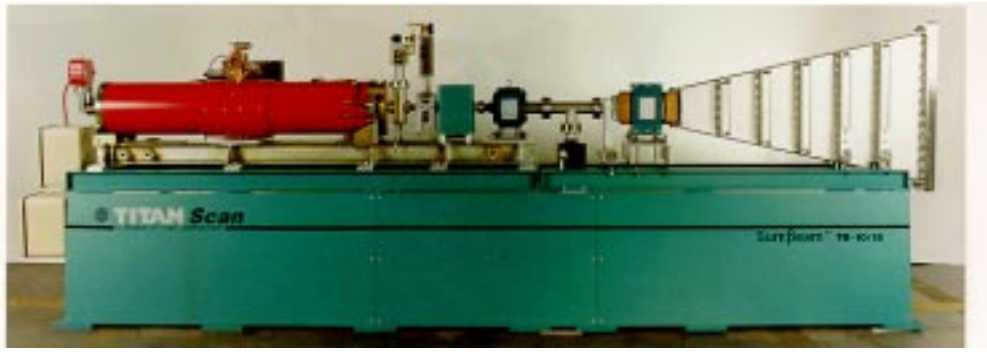
E-Beam Primer

- Radiation generated by on/off switchable accelerators
  - e-gun creates electrons via heat and voltage
  - beam of electrons electromagnetically accelerated, focused, guided
  - power conditioning system powers e-gun and accelerator
- Penetration depth depends on beam energy & product density
- Product throughput is proportional to beam current
- Products *do not* become radioactive if beam energy is limited to ~ 10 MeV
- *Absorbed* dose measured in kGy; 1 kGy = 1 kJ/kg = 0.1 MRad



Electron Accelerators

Acsion Industries IMPELA



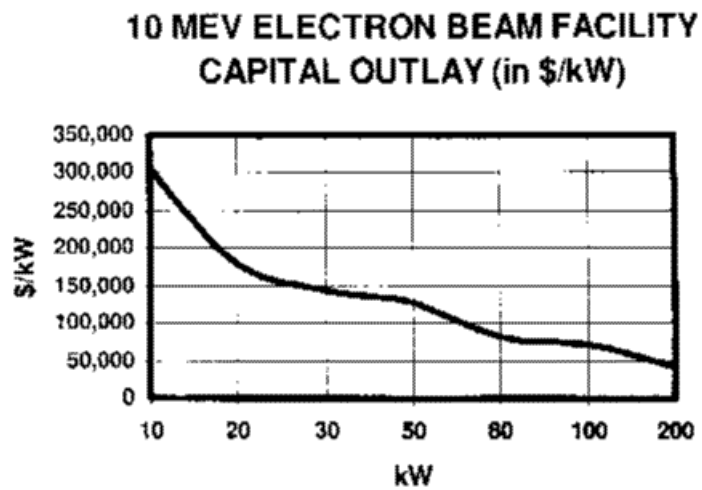
Titan SureBeam ®

BioSterile SB5000

IBA Rhodotron

Economics

- Aero applications economically very attractive
  - Six independent cost analyses show estimated savings from 13% - 65%, excluding part count reductions
  - Sensitivity analysis favorable
  - As-manufactured cost validation underway
- Need to model economics for selected non-aero applications
  - Automotive manufacturing & engineered wood appear to be good candidates



Materials

- Competent epoxy resins/adhesives available
  - Shear & toughness enhancements underway
  - Extreme environment effects under study
  - Production scale-up, qualification on horizon
  - Need greater focus on adhesives
- Acrylates cure well, frequently used in coatings, but not suitable for most structural applications
- Vinyl ethers/esters screened, show promise for some cases
- Polyimides and bismaleimides not encouraging
- Work is needed on inexpensive structural resins, e.g. urethanes, polyesters
- Resin development for engineered wood products also proposed

Processing

- Attributes:
  - Fast
  - Clean & efficient
  - Long resin pot life
  - Selectable cure temp
  - Interruptible cure
  - Materials integration flexibility; different resins/fibers, metal inserts/fasteners, low temp materials

- Needs:
  - Reliable, flexible, automated, inexpensive equipment
  - Inline processing facilities
  - User-friendly, fast simulation tools
  - Processing standards
  - Cure monitoring and/or non-contact real-time dosimetry
  - High-efficiency x-ray generators

Tooling

- E-beam curing offers new, inexpensive tooling options
  - Organic matrix composites, polymers, foams
  - Castable ceramics
  - Plasters, wax
  - Wood, paper
- Attractive for “lost core” processes
- High potential cost savings for prototyping and low volume production
- CTE issues minimized
- Radiation attenuation & stability are important
- Need high production volume tooling w/class A surfaces

Environment, Safety, & Health

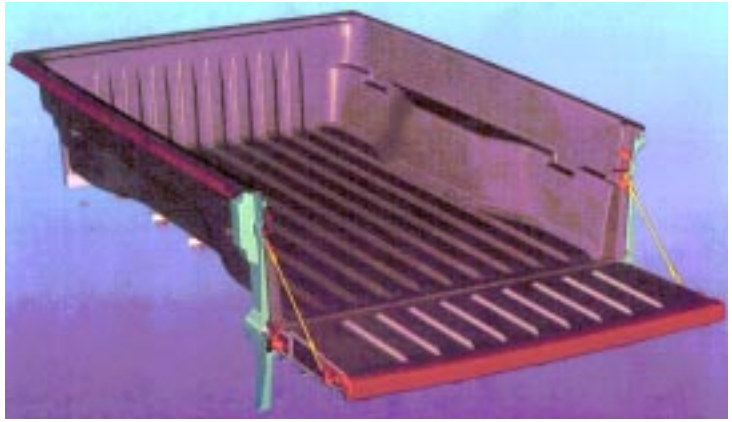
- Up to 90% reduction in energy required for curing
- ~ 90% reduction in VOC production & emissions
- Significantly reduced toxins & carcinogens
- Reduced solid/liquid waste stream
- Radiation hazard well understood & controlled
- Ozone ventilation required

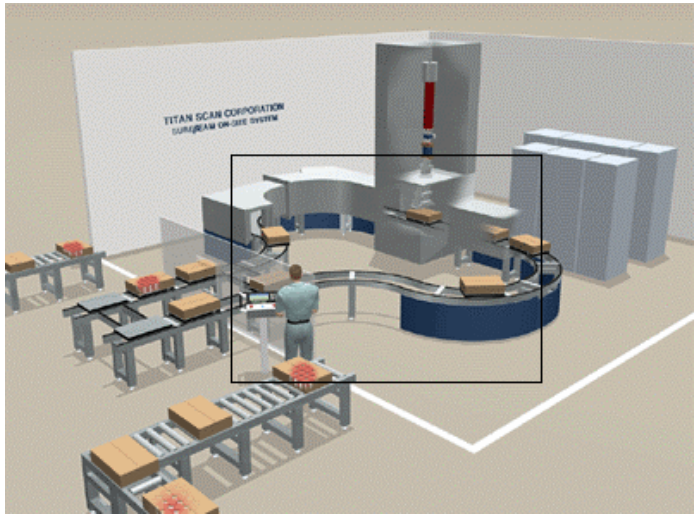
3 Prospective Automotive Applications

- Adhesive bonding truck boxes
- Prototyping
- Body-in-white

Adhesive Bonding Truck Boxes

- Composite truck boxes can be *rapidly* bonded to the truck frame
- 1 - 4 minute bonding cycle times readily conceivable
- In-line joining station similar to presently available onsite food pasteurization system
- There are several potentially e-beam curable adhesives; epoxies most mature





	Bonding Cycle Time		
ROM Unit Costs*	4-min	2-min	1-min
Amortization	$10	$7	$5
Power	$0.50	$0.50	$0.50
Maintenance	$1	$0.70	$0.50
ROM Unit Cost (excludes labor)	$12	$8	$6

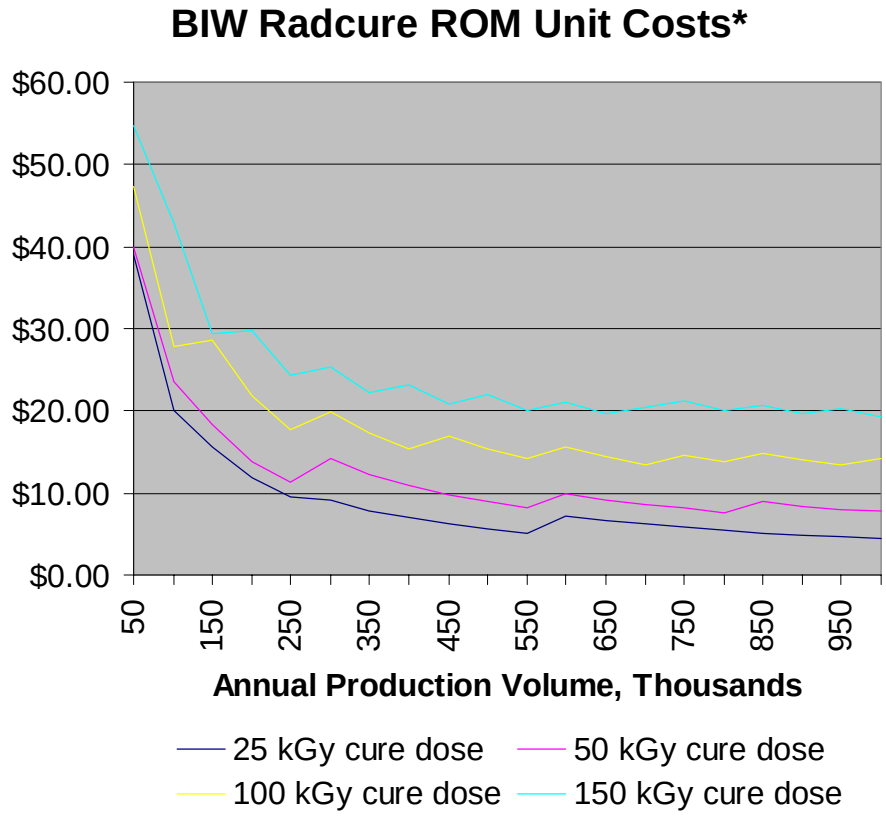
*7500 hr/yr operation, 5-yr amortization @ 12%, 150 kGy dose, compact truck box

Prototyping

- Enables use of inexpensive, “soft” tooling for prototype manufacturing
- Tooling durability not critical for prototyping; tooling cost is
- Enables the use of multiple materials and metallic inserts with a single cure cycle
- Rapid tool manufacturing shortens prototype cycle
- Curing can be performed by a toll processor

Body-in-White

- Rapid cure: 1 - 5 min cycle for 300# BIW using a commercial 150 kW accelerator
- Can commence subsequent assembly ops immediately
- In-line on factory floor
- Tooling can be removed after gellation
- Low curing labor costs



*Includes amortization, utilities, & maintenance; excludes materials, labor, G&A. Basis - 5-yr amortization at 12%, 7500 hr/yr operation, 300 # composite BIW, 50% beam utilization, utility rate $0.10 per kW-hr

Summary

- E-Beam curing is an enabling new composites processing technology
- E-Beam curing has been shown to provide compelling cost reductions for aero applications
- E-Beam curing appears to be well-matched to specific automotive applications, offering very short cycle times, “green” manufacturing, and attractive economics

Acknowledgements

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R&D Needs

- Adhesive bonding truck boxes
  - Adhesive development/optimization
  - Rigorous economics case study
  - Irradiation process design/simulation
  - Facility customization
- Prototyping
  - Materials development
  - Tooling design, molding/compression techniques
  - Irradiation process design
  - Economics case study
- BIW
  - Materials development
  - Rigorous economics case study
  - Robotics/articulation
  - Tooling design
  - Irradiation process design/simulation
  - Facility design for high volume, parallel conveyance