OPPORTUNITIES FOR ELECTRON-BEAM COMPOSITES PROCESSING APPLIED TO FUTURE ARMY APPLICATIONS

Steven H. McKnight, Bruce K. Fink, and James M. Sands
U.S. Army Research Laboratory

Oak Ridge National Laboratory
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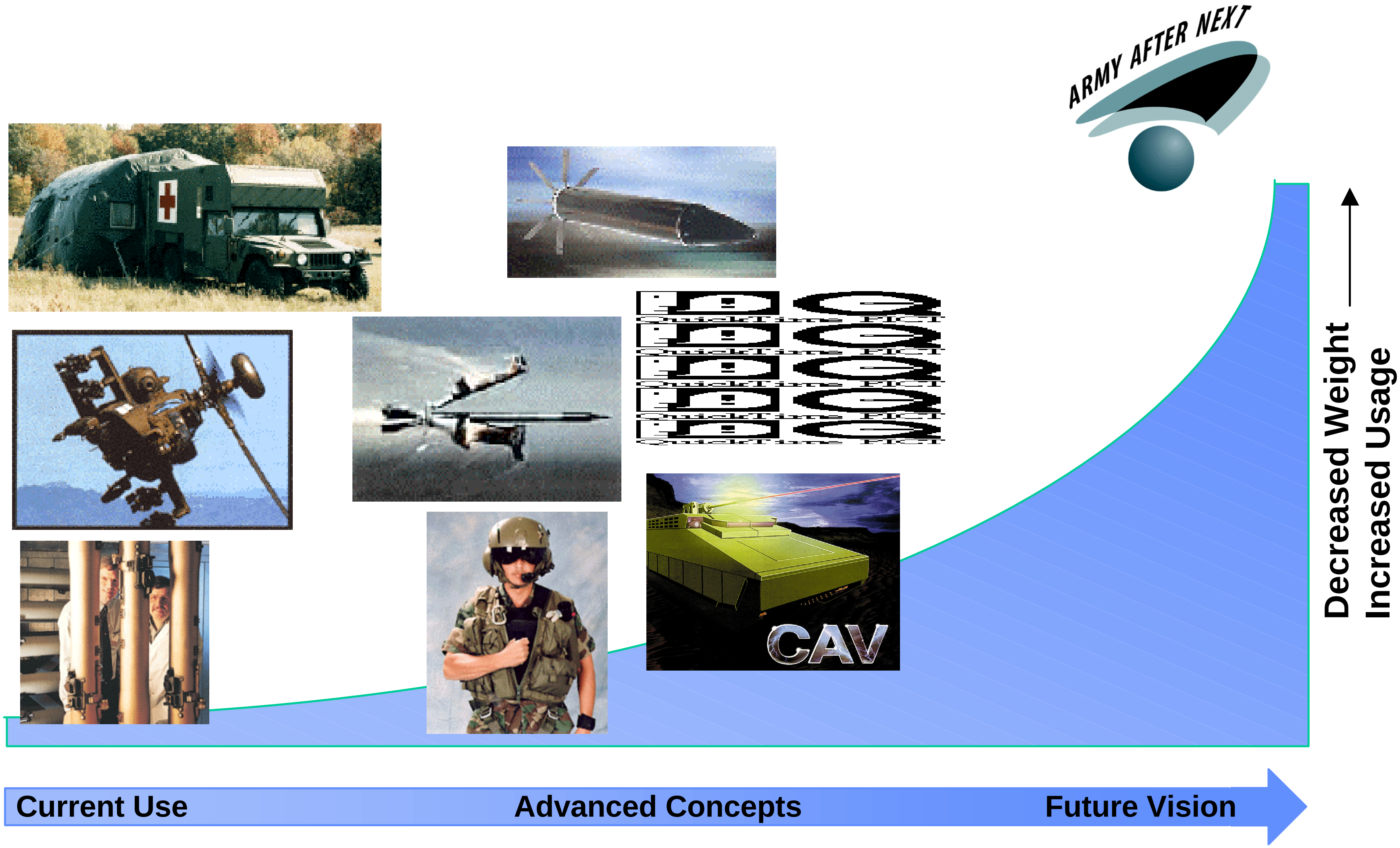
PRESENTATION OUTLINE

- Army composites and adhesives research
  - Overview of activities
  - Research Goals
  - Role of affordable processes
- Current e-beam research and development programs
  - SERDP "Green Composites"
  - Army Mantech
  - Composite Materials Research Cooperative Agreement
- Highlights and progress
- Opportunities and issues

PROJECTED ARMY USE OF POLYMER MATRIX COMPOSITES



ARMY USE OF COMPOSITES

- **Traditional Army Applications: Value-Added Assets**
  Cost is justified to meet performance
  - **Property driven**
  - **Cost is important but performance is metric**
  - **High QC, extensive database, consistency**
  - **Growth is incremental**

- **Emerging and Projected Army Applications**
  - **Weight and performance driven**
  - **More and varied applications for PMC exploitation**
  - **Cost will drive insertion in many applications**
  - **Effect of property variability depends on application**
  - **Non-traditional composite properties may drive design**

OVERVIEW

- **Army uses PMCs in varied applications**
- **Cost issues are complex for existing applications**
  - **Balance of performance and cost**
  - **Raw materials vs. production (Cost per manufactured article)**
  - **Life-cycle arguments may justify further use**
- **Incremental increases in properties or decrease in prices desirable**
  - **Allow for further performance enhancements**
  - **New “low-tech” applications/markets (ie bridging, shelters, containers, etc.)**
  - **Property “consistency” levels may be reduced in certain applications**
- **Real driver for composites is Army After Next concepts**
  - **Revolutionary materials solutions are needed**
  - **Incremental progress will fall short**
  - **Limited resources for materials development**

ARMY AFTER NEXT: BOTTOM LINE

KNOWLEDGE AND SPEED

- **Lighter**
- **Faster**
- **Deadlier**
- **Smarter**

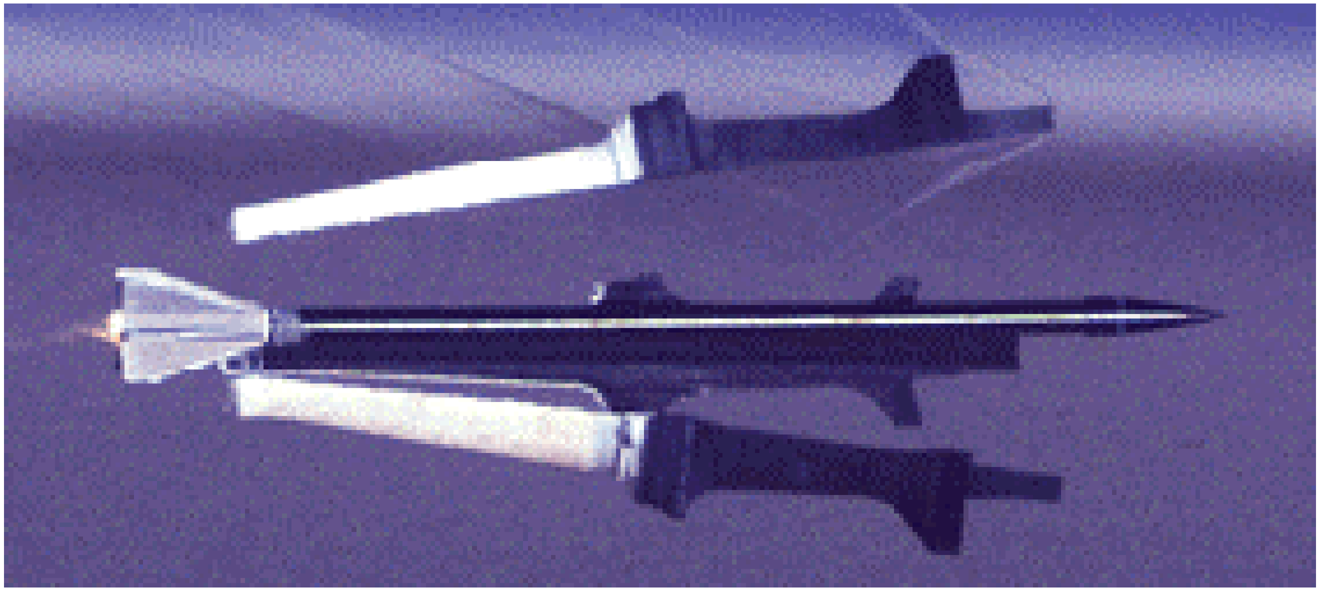
…. While maintaining affordability, justifiability, and sustainability

INTERCEPTOR SYSTEM REQUIREMENTS DRIVE MATERIALS NEEDS

System Level Requirements	Subsystem Level Requirements	Materials Requirements
• Discrimination And Accuracy	• Stable seeker platform	• Ultrahigh Modulus PMCs (e.g. M60J)
• High burnout Velocity	• Light Airframe	• High specific strength and Stiffness composites
• Terminal Stage High Divert Capability	• Light Airframe	• High specific strength and Stiffness composites
• Acquisition Cost	• Low cost Airframe	• Low cost fabrication Methods
• Life Cycle Cost	• High kill ratio; Fewer KVs	•High specific strength and Stiffness composites

PMC USE IN ORDNANCE APPLICATIONS: M829A2

- Army's anti-tank weapon of choice
- Sabot is a major use of composite material (385,000 lb/yr.)
- Compression Driven
  - Straight fibers
  - High quality: (0.5% voids, 63% Vf)
- High degree of QC (UT-NDE, CAT-NDE, testing)
- Numerous processing Improvements - Affordability



ORDNANCE SYSTEM AND MATERIALS REQUIREMENTS

System	System Requirements	Subsystem Level Requirements	Materials Requirements
• SABOT	• Enhanced Lethality •Deployment ease	•Reduced parasitic Mass •Reduced weight	• High quality, high compression strength
• Artillery	• Enhanced Lethality •Deployment ease	•Lightweight casing; fins for Stability	• High quality, high compression strength • High specific strength and stiffness for fins
•Gun Barrels And Mortars	•Accuracy, Stability, Fast fire	•Lightweight stiff materials; high temperature performance	• High performance composites High temperature (600-800°F) resins

- Compression drives requirements
- Significant volume potential in ARTY rounds

AAN GROUND VEHICLE REQUIREMENTS WILL DRIVE MATERIALS REQUIREMENTS

System Level Requirements	Subsystem Level Requirements	Materials Requirements
• Increased Fuel Efficiency (4-5X)	• Reduced Weight (60%) • Efficient engines	• Lightweight hybrid materials for vehicle structure
• Increased Speed	• Reduced Weight	• Lightweight hybrid materials for vehicle structure
• Ballistic Protection	• APS for KE • Lightweight passive Armor for frag and small caliber	• Low areal density armor (60% reduction from CAV) -Hybrid: ceramic, PMC, metal -High "specific ballistic" props
• Deployability	•Total Weight ˜ 20 Tons	•Lightweight hybrid materials

- Lightweight ballistic solution is key
- Need new reinforcements: organic, carbon, other?
- Revolutionary concepts are required

Maturation of Composite Armor Toward AAN

AAN requires revolutionary changes in:

- range of protection levels
- ballistic performance
- damage tolerance
- affordability
- structural performance
- fire performance

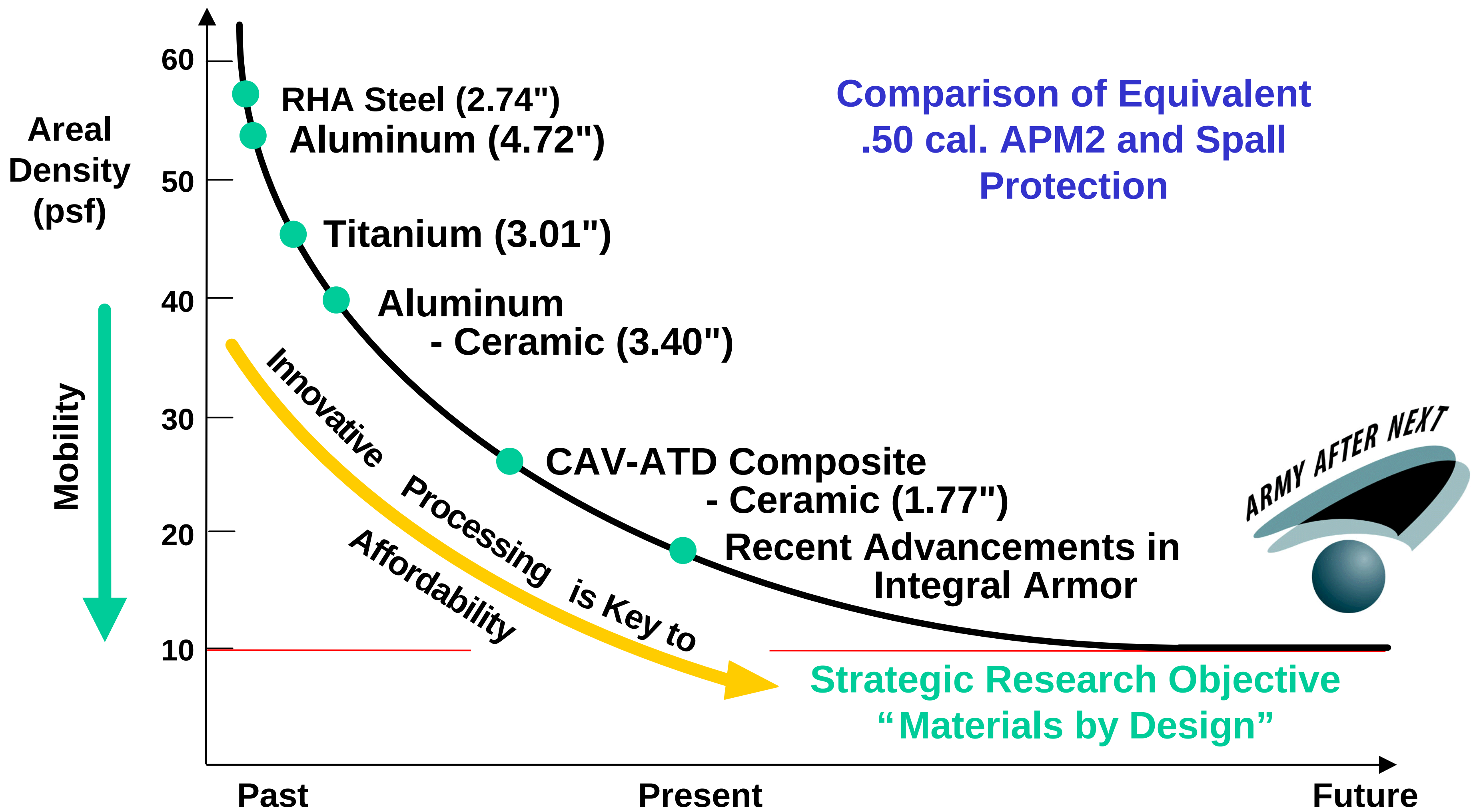
Monocoque

Appliqué

Integral

Enabling technologies for materials-by-design include lightweight, high-strength multifunctional composites for integral armor.

Revolutionary Composite Armor Improvements



TECHNICAL ISSUES: LIGHTWEIGHT INTEGRAL ARMOR

- **Integral Armor: System must bear structural loads and provide passive ballistic protection for varying threat levels.**
- **Ballistic performance vs. weight generally drives design.**
  - **Shock wave management in multilayered anisotropic materials systems is not well understood.**
  - **Parametric empirical studies of OTS materials are expensive and time consuming.**
  - **Energy absorption mechanisms at HSR are not quantified.**
  - **Multifunctional systems approach: "composite-composite"**
- **Difficult path forward to get weight reductions and maintain protection.**
  - **Revolutionary concepts are required.**
  - **New materials are an option.**
  - **Modeling is needed to identify trends and point to solutions.**
- **What properties do we need in composites (fibers) to get optimum structural/ballistic performance in the lightweight armor solution?**

OPPORTUNITIES

- **Army will increasingly rely on affordable composite structures to meet weight and performance goals**
  - **Combat ground vehicles**
  - **Ordnance, missiles, and BMD**
  - **Bridging, shelters, support vehicles**
  - **Rotorcraft**
- **E-beam opportunities for OEM assembly and fabrication**
  - **Enables new processes and hybrid materials solutions**
  - **Reduces costs through step consolidation and reduced cycle time**
  - **Lower costs may be accompanied by improved performance**
- **E-beam opportunities for remanufacture and repair**
  - **Long shelf-life resins-reduced adhesives acquisition costs**
  - **Higher repair yields result in improved logistics**
  - **Higher performance repair materials**

Problem

- **increasing use and complexity of composites on DOD platforms**
  - **increased waste stream(trim, consumables, VOCs) for repair**
  - **increased hazardous waste stream due to shelf-life expiration**
  - **increased dependence on autoclave (NO_X, refrigeration)**
- **non-polluting damage repair techniques is a DOD responsibility**

Objective

To research, develop, and demonstrate affordable and environmentally-friendly composite repair and remanufacturing technologies for stand-alone repair of DOD structures without creating new environmental problems.

Pay-Off

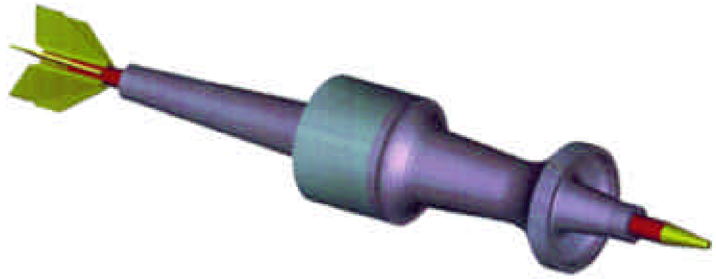
Potential annual savings of $15B (1998) predicted for 2028.

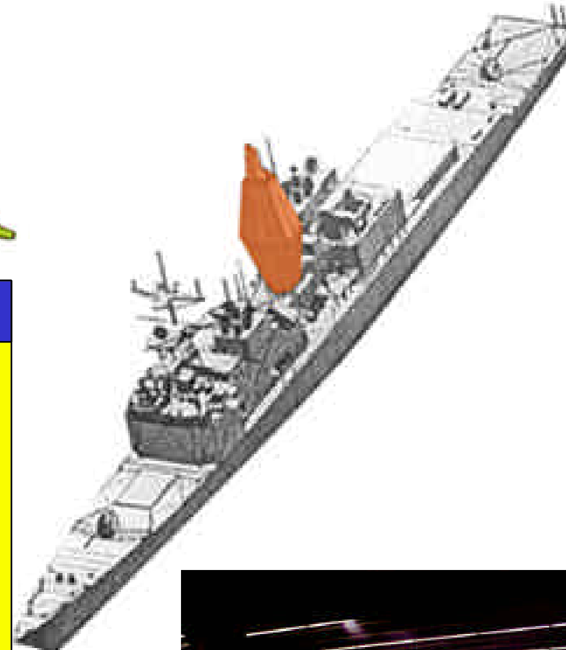
[from Newton, et al., "Non-Polluting Composites Repair and Remanufacturing for Military Applications: An Environmental and Cost-Savings Analysis," Special Report to SERDP, Army Research Laboratory, September 1998.]

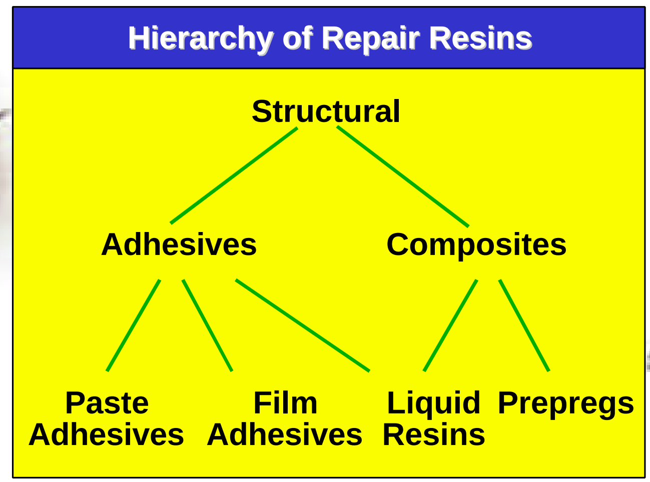
MATERIALS TO APPLICATIONS

ARL

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research



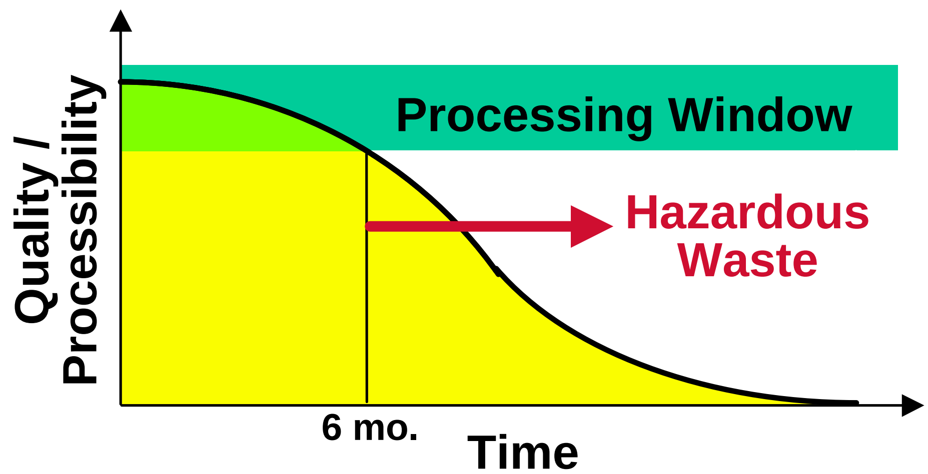


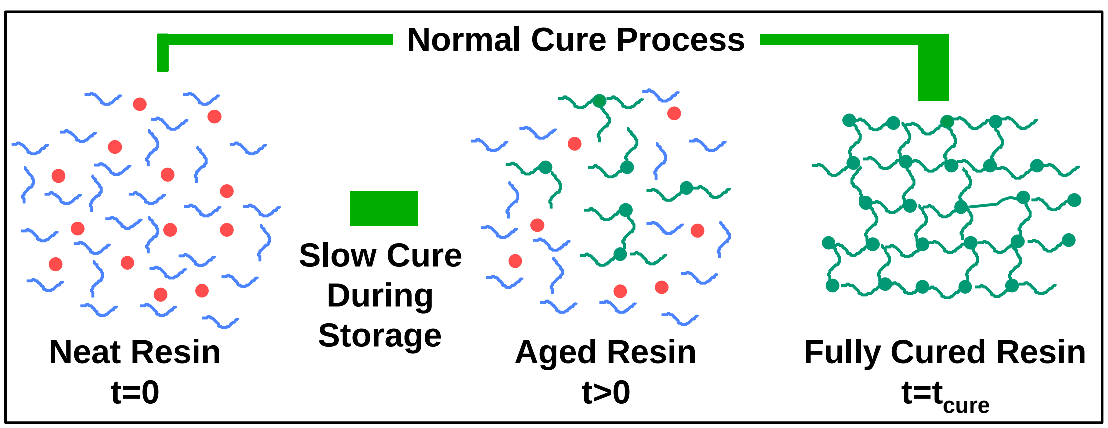


SIGNIFICANCE OF SHELF LIFE

"The Navy estimated that 40 to 60 percent of the adhesives procured for advanced composite repair were spoiling before they could be used."

Report on Audit of Repair of Weapon Systems Containing Advance Composite Materials, Report No. 92-139, Inspector General, Department of Defense

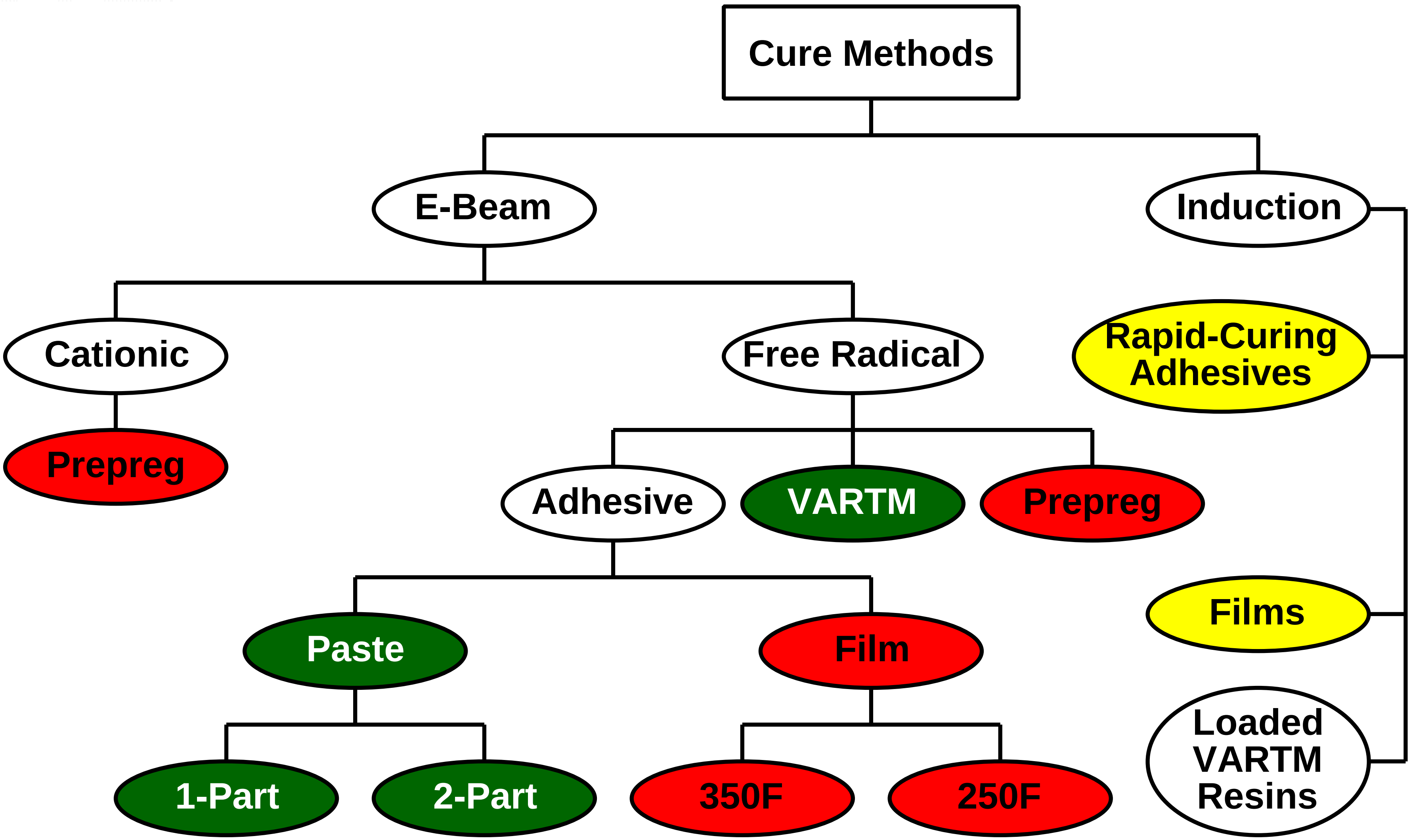




RESIN SYSTEMS BEING FORMULATED

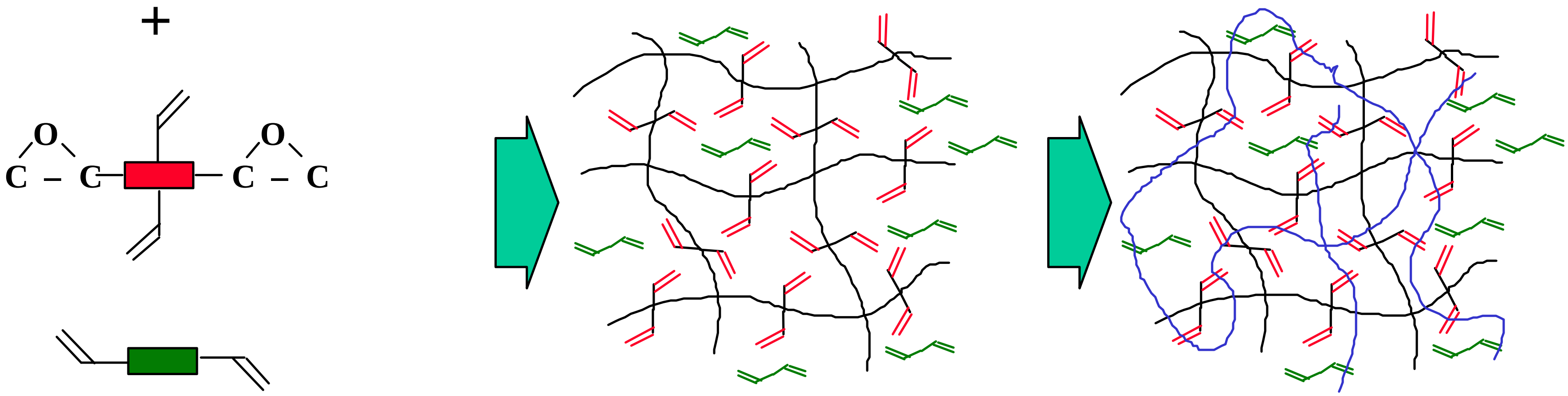
Strategic Environmental Research and Development Program

Improving Mission Readiness Through Environmental Research



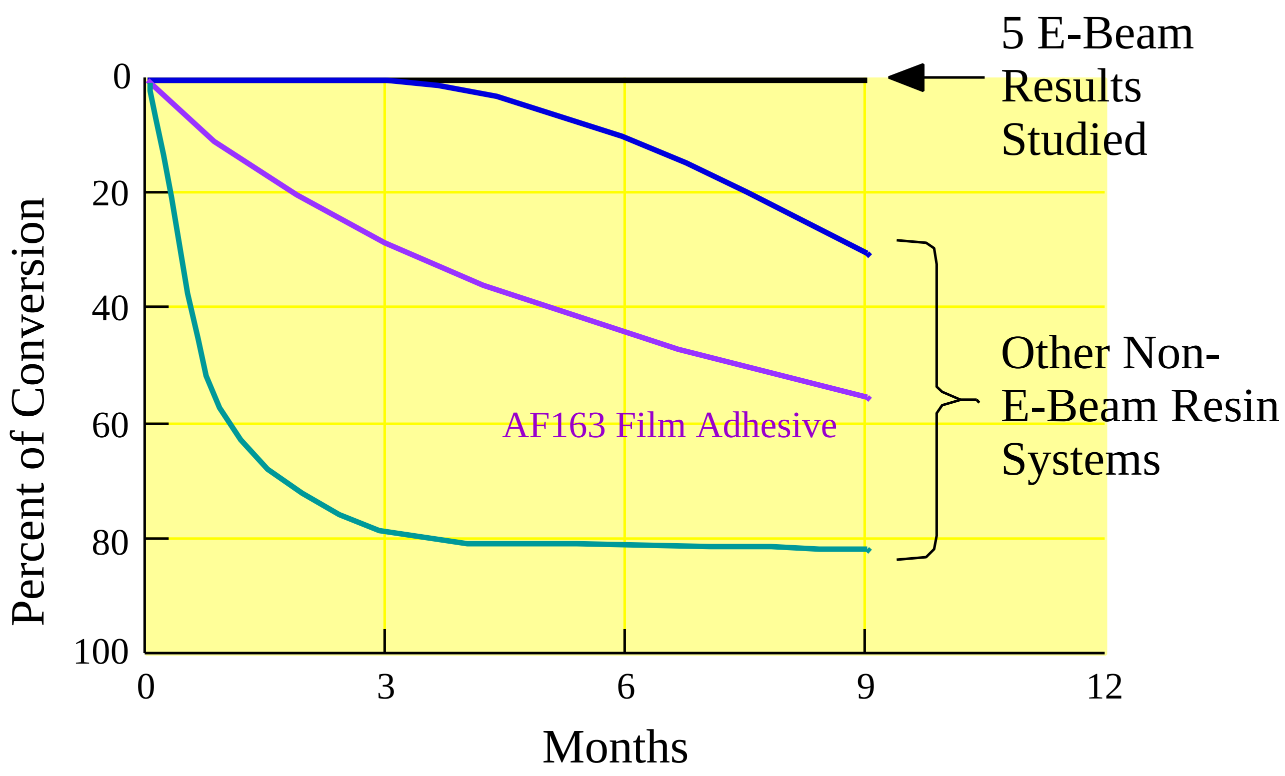
CURE PROCESS FOR AN EPOXY-ACRYLATE E-BEAM RESIN

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research



Reactants | **Heat to C-stage** | **Radiation Crosslinking**

RESULTS OF ONGOING RESIN AGING STUDY

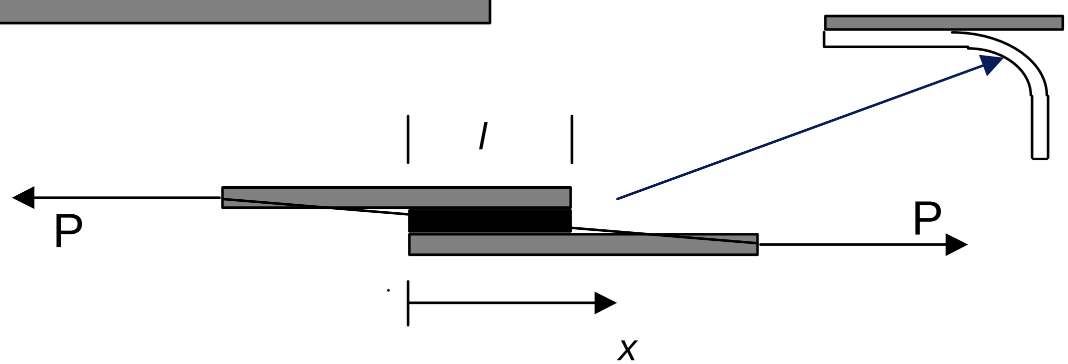


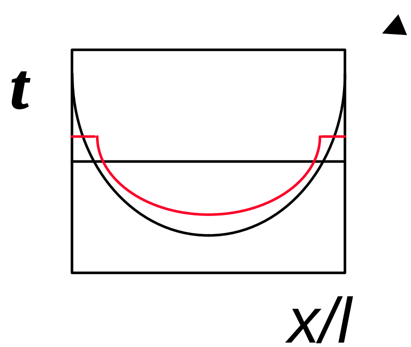
ADHESIVE JOINTS

Structural Adhesives Attributes:
1) **Stiffness - transfer of load**
2) **Ductility - elastic/plastic behavior**
3) **Toughness - resist peel stresses**

Eccentric loading induces
out of plane loads at joint edge

"Peel Stresses"



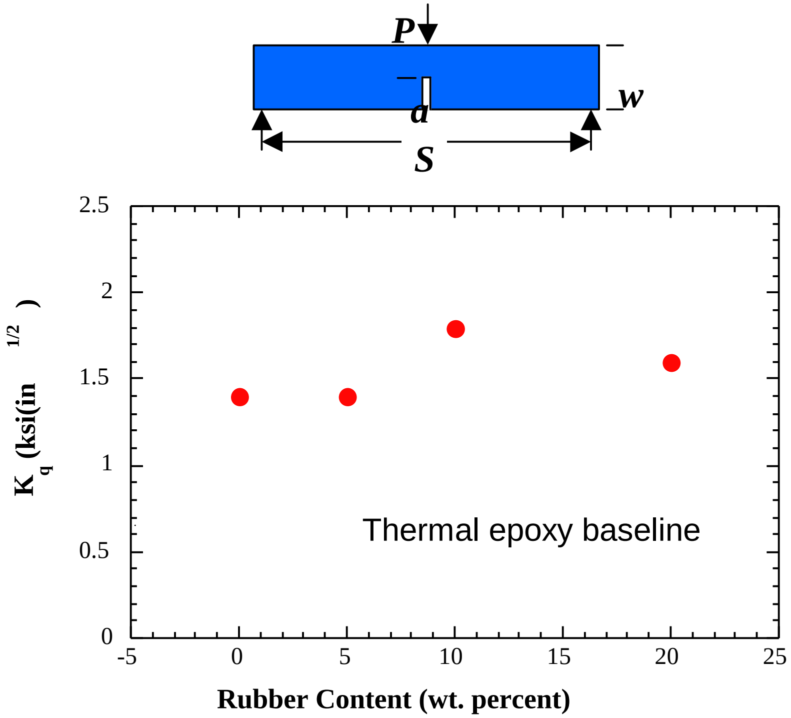


Elastic-Plastic behavior lessens
stress concentration

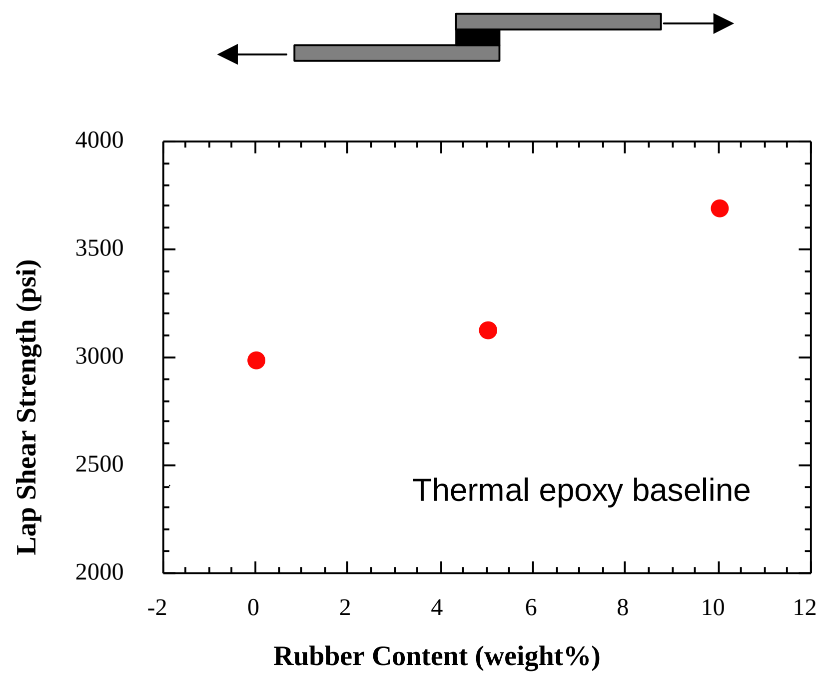
Bottom Line
Adhesives must be toughened

TOUGHNESS VS. JOINT STRENGTH IN A MODEL E-BEAM ADHESIVE SYSTEM

ASTM D 5045-93

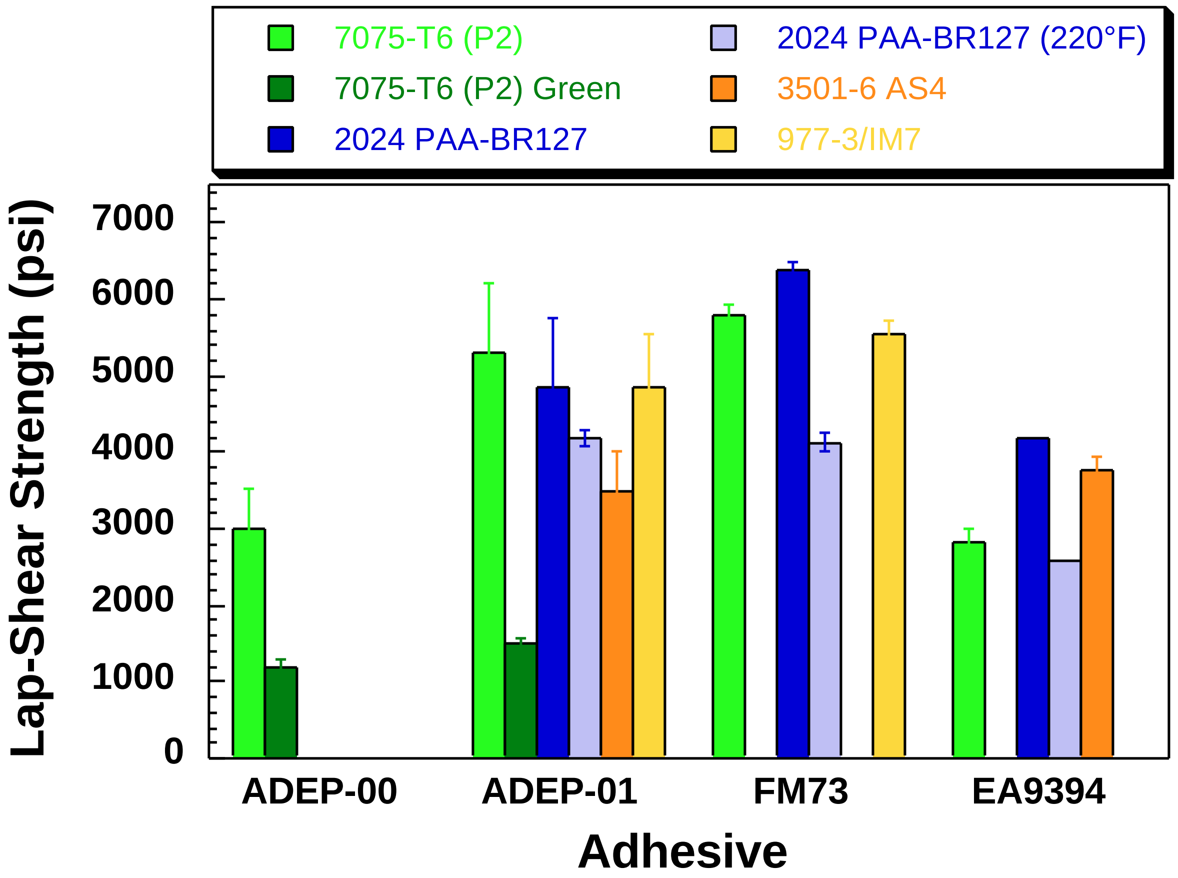


ASTM D 1002



- **P2 etched 2024-T3 aluminum**
- **Model epoxy-acrylate IPN adhesive (not optimized)**
- **Plane strain fracture measurements**
- **All joint failures cohesive**

ARL'S ADEP ADHESIVES VERSUS COMERCIALLY AVAILABLE EPOXIES



Adhesive	Tg
ADEP-00	123°C
ADEP-01	121°C
FM73	95-105°C
EA9394	65-70°C

- "Green" ADEPs are tested after thermally staging prior to e-beam irradiation
- Data without error bars taken from product literature or other publications
- Material from actual bondlines used for DSC Tg measurements

ISSUES AND BARRIERS

- Resin properties must be improved for some Army Applications
  - Processing properties
    - Viscosity control
    - Consolidation and wet-out
    - Cure kinetics and polymer structure/properties
  - Toughness
  - Modulus retention at elevated temperature
- Composite and adhesive database is lacking
  - Framework and standards on presentation of data
  - SACMA, MIL-17, or other vehicle for dissemination of information
  - Qualification/Certification: Materials and performance specifications
- Need for fundamental research for long-term improvements
  - Cationic cure mechanisms and network structure
  - Toughening mechanisms and network design
  - Adhesion and interphase (fiber-matrix and substrate-adhesive)
- Limited resources for technology investment