U.S. Army Research Laboratory

U.S. Army Tank-automotive and Armaments Command

University of Delaware Center for Composite Materials

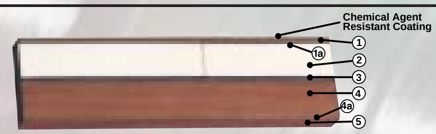
COMPOSITE ARMOR

Providing Multifunctional Materials for Future Ground Vehicles

The U.S. Army Composite Infantry Fighting Vehicle and Composite Armored Vehicle programs introduced the concepts of monocoque and integrated composite armor, respectively. These programs set baselines for future improvements in lightweight protection, signature management, structural integrity and cost-effective manufacturing for ground vehicle applications. Composite armor technologies will provide future ground vehicles with multifunctionality at significantly reduced weights.

The Army Research Laboratory (ARL), the University of Delaware Center for Composite Materials (CCM), and Tuskegee University have teamed to study various aspects of composite armor:

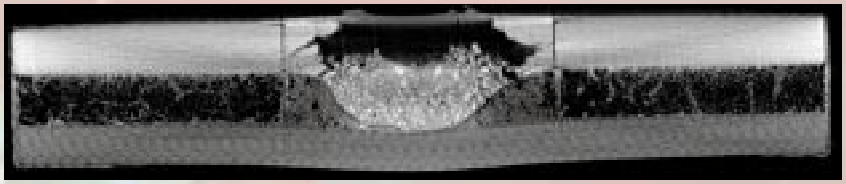
- The effects of fiber sizing, resin properties, stitching, tile adhesion, and elastomeric sublayer properties on ballistic and post-ballistic performance
- Thick-section processing analysis, including RTM flow, cure, and process-induced residual stress and warpage modeling
- Innovative cost-reducing processing techniques
- Repair
- Cost analysis
- Quality and process sensing and control



Layer	Material	Function
1	S-2 glass/epoxy composite	Structural integrity Protection of EMI shielding layer Protection of ceramic tiles from low-velocity impact
1a	Classified	Signature management
2	Al_2O_3 (aluminum oxide) ceramic armor tile	Ballistic protection
3	EDPM elastomer	Multiple ballistic impact protection (by shock-wave attenuation) Damage isolation to single ceramic tile (Protects adjacent tiles)
4	S-2 glass/epoxy composite	Structural integrity Bending failure reduction of ceramic tiles
4a	Metallic screen	Electromagnetic interference (EMI) shielding
5	Glass/phenolic composite	Spall reduction Fire, smoke, and toxicity protection

Composite Armored Vehicle Composite Integral Armor

This composite integral armor architecture was developed under the Composite Armored Vehicle Advanced Technology Demonstration Program with United Defense Limited Partnership. While this architecture meets the needs of the CAV, several ARL programs focus on developing improvements in cost-effective manufacturing and in structural, ballistic, signature, fire, smoke, and toxicity performance.



Lightweight composite structural armor solution incorporating aluminum metal foam impedance layer for improved projectile defeat, lower dynamic deflection, and enhanced ballistic shock attenuation.

Virginia Tech University

University of Delaware

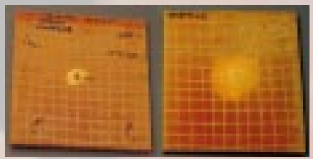
Tuskegee University

U.S. Army Tank-Automotive RDE Center

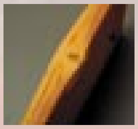
U.S. Army Armament RDE Center

United Defense

United Defense Limited Partnership



7.03 psf S-2 glass/SC-4 resin armor plate - stitched
Stitch spacing + 1 inch stitch gauge = 4 threads per inch



Cross-section of stitched S-2 glass/SC-4 resin armor plate (delaminations highlighted)

STITCHING

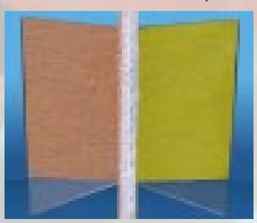
Performance Enhancement

Performance enhancement research focuses on optimizing fiber sizing, resin, and interphase properties; improving tile-resin adhesion; and quantifying the effects of through-thickness reinforcement for improved damage tolerance. The research has focused on establishing a fundamental understanding of energy-absorbing mechanisms to improve the performance of future appliqué and integral armor applications. High strain-rate characterization studies of integral armor and its individual components are supporting ongoing ballistic modeling efforts by providing insight into damage mechanisms. Extensive ballistic testing has provided important data on ballistic resistance for various resins — including vinyl esters, polyester, toughened epoxies, and urethanes— and damage tolerance due to through-thickness stitching. Further modeling and testing is allowing improvements in ceramic tile confinement, composite backing stiffness, and elastomer layer thickness.

Integral Armor Processing

Innovations in the processing of integral armor such as Co-Injection Resin Transfer Molding (CIRTM), process-friendly phenolic and urethane resins, and large-scale, multiple-plane SMARTweave sensing are being combined to produce the latest in composite integral armor systems for vehicular and personnel armor. CIRTM, an innovative method of simultaneously injecting multiple resins into a multilayer composite armor structure, provides several benefits in cost and performance. Simultaneous injection of multiple resins, needed for the different composite layers, provides significant cost savings by reducing process steps. This method also allows through-thickness reinforcement of a composite layer in the form of aramid stitching.

CO-INJECTION RESIN TRANSFER MOLDING (CIRTM)



Cross-section cut view (with mirrors showing opposite surfaces) of a composite panel co-injected with phenolic (left) and vinyl ester (right).

EMBEDDED SENSORS FOR INTELLIGENT PROCESS CONTROL AND DAMAGE DETECTION

BALLISTIC TESTING

Ultrasound scan of glass/epoxy composite after ballistic impact showing severe delamination (Baseline) and lack of delamination with diffusion-enhanced adhesion (DEA).

Process Modeling

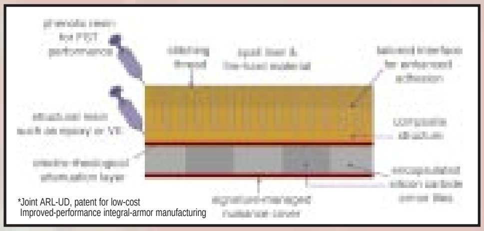
Developments in process modeling, sensing, and process control are critical to the effective implementation of cost-effective integral armor processing.

Recent Innovations Include:

- 3-D RTM flow modeling and sensing for vacuum-assisted RTM techniques such as SCRIMP
- experimentally validated models of the complex cure behavior of room-temperature-curing vinyl-ester resin systems and systematic procedures for modeling new resins
- neural-net simulations of RTM flow
- modeling of the relationship between ionic transport in RTM resins and their transient viscosity and cure behavior

Work continues on residual stress and warpage models and flow model inversealgorithms for process control.

FUTURE COMBAT VEHICLES



ADVANCED HIGH MASS-EFFICIENCY MULTIFUNCTIONAL COMPOSITE ARMOR DESIGNS

Cure and Joining

Alternative methods of cure such as electron beam and induction heating offer new opportunities for “getting out of the autoclave.” Diffusion-enhanced adhesion (DEA) offers the ability to use proven fusion bonding techniques to provide tough bonds for composite armor components. These techniques are being aggressively pursued through this collaborative program.

FOR FURTHER INFORMATION

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Composite Materials — Enabling the Vision!