

Presentation 8 • November 18 • 10:00 AM

Lightweight Composite Integrated Structural Armor

~ presented by ~

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CW COMPOSITESWORLD

NOVEMBER 17-18

HIGH-PERFORMANCE FIBERS 2009

Doubletree Guest Suites Historic Charleston SC

“High Performance Reinforcements for Integrated Structural Armor”

Al Chan

High-Performance Fibers 2009

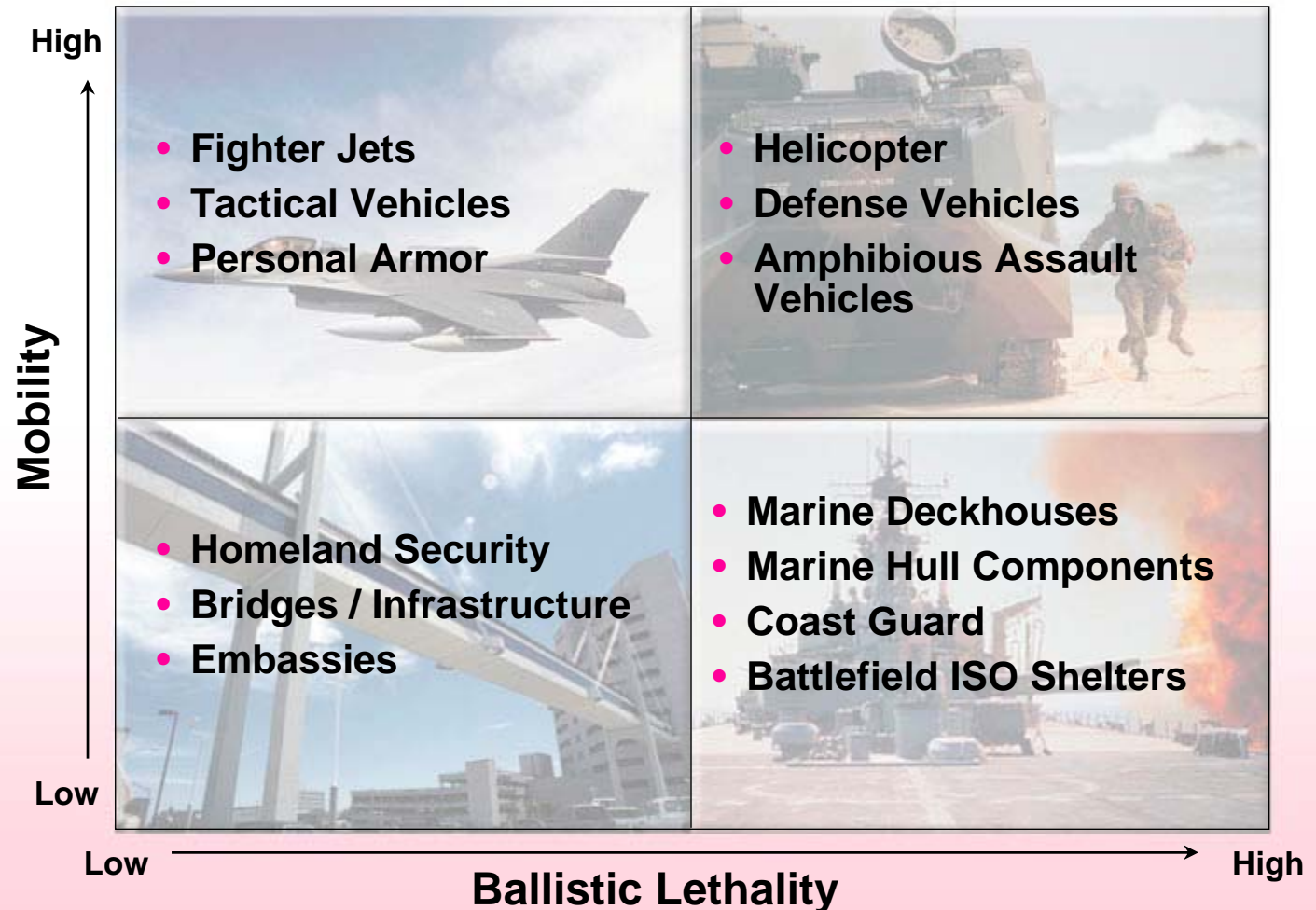
October 18, 2009



OCV™ Reinforcements

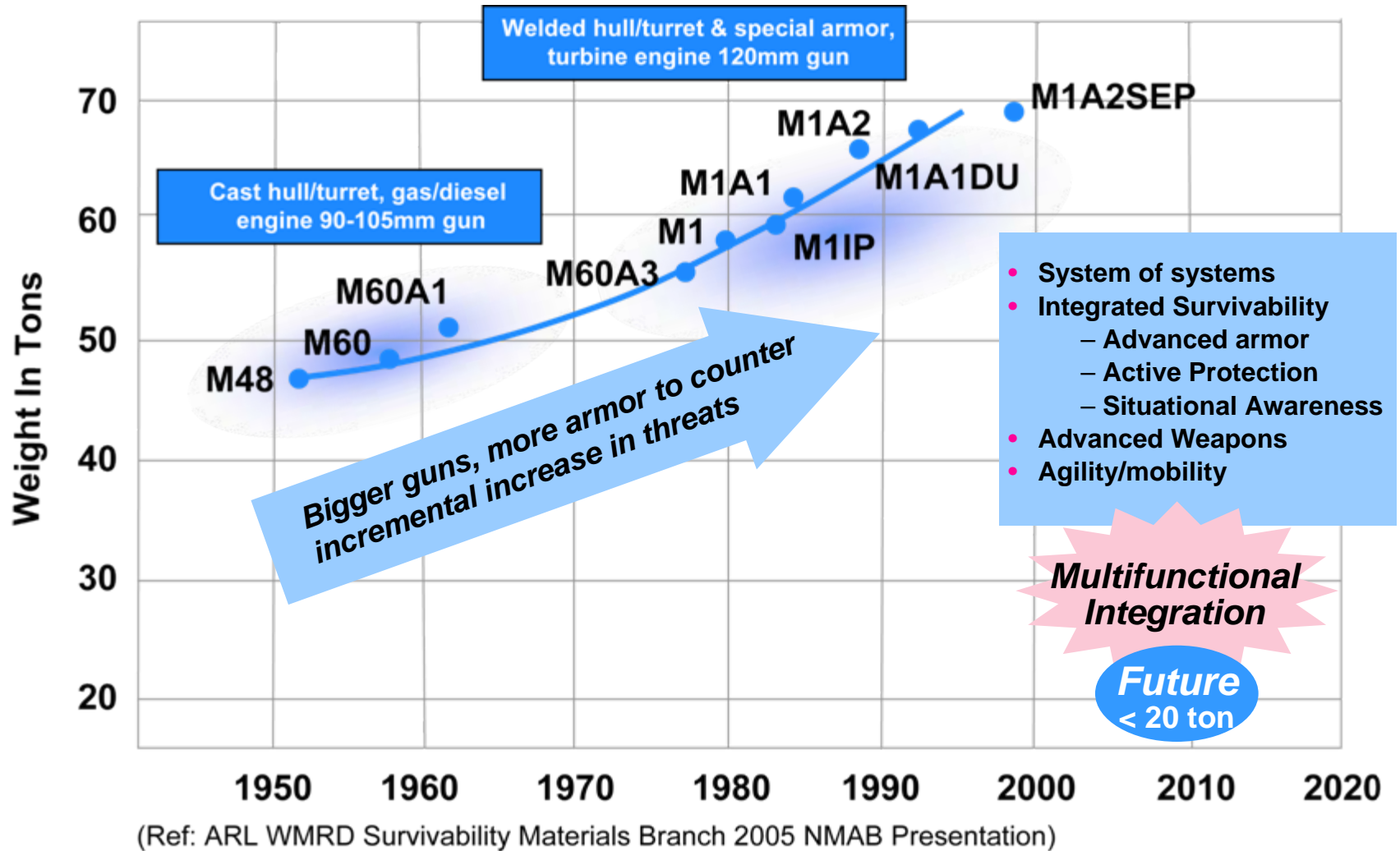
DELIVERING SOLUTIONS | TRANSFORMING MARKETS | ENHANCING LIVES

Lightweight Composite Material Enables



Improved Mobility and Ballistic Performance

Tactical Mobility and Strategic Deployability Drive the Need for Lighter Weight Vehicles



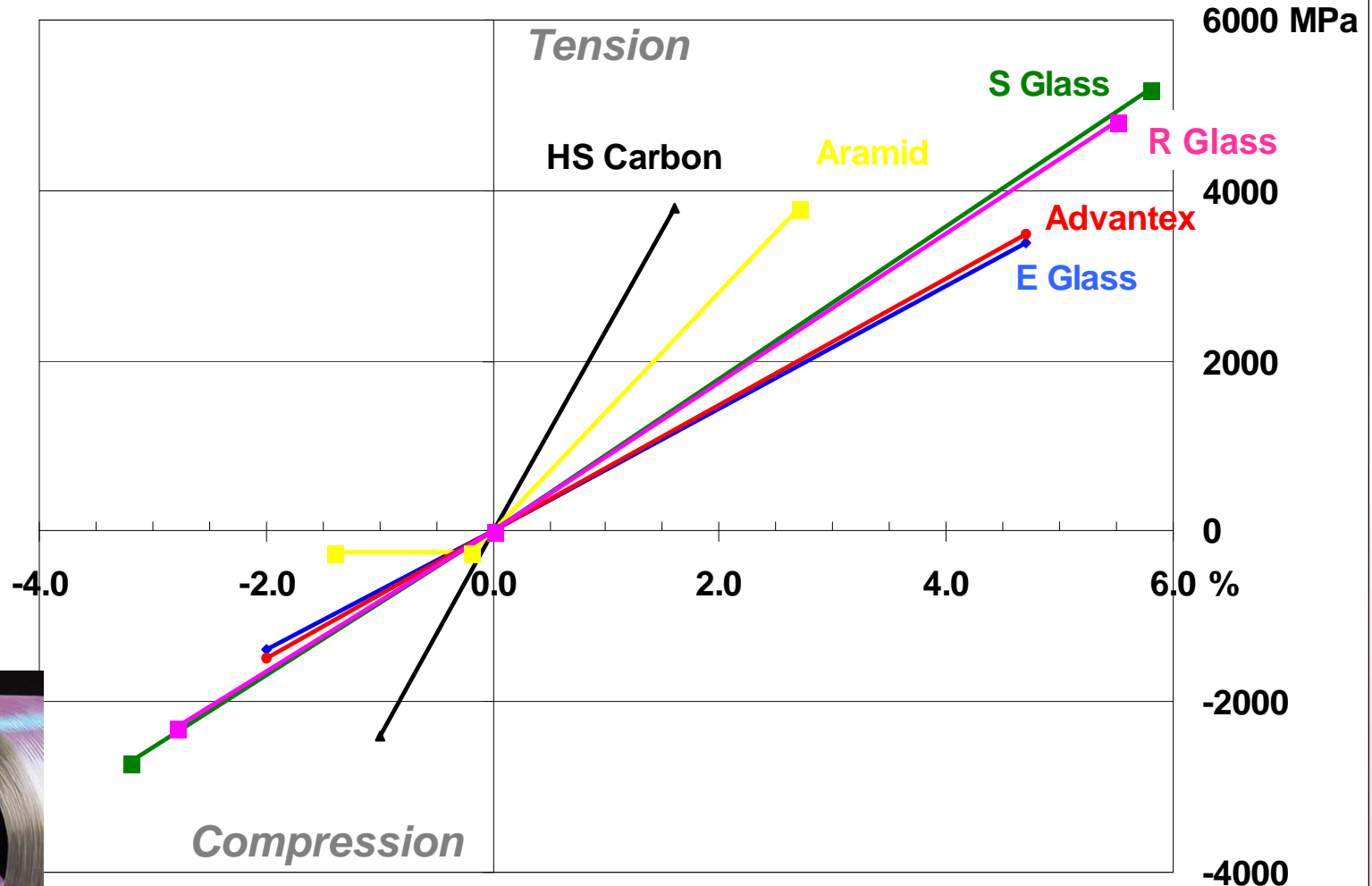
Stronger for Better Protection in Lightweight Composite Structures



Fiber surface silane chemistry provides adhesive compatibility engineered for ballistic and structural performance



Typical Stress-Strain Curves of Fibers



Glass and Melting Technology Innovation

- **1939: OCV invented E-glass**
 - Boron added to glass for electrical properties
- **1968: OCV developed S-2 Glass®**
 - High Performance Glass (high melting power needed)
 - Small capacity furnaces due to limits in melting technologies
- **1980: OCV developed E-CR Glass®**
 - Corrosion resistant glass.
- **1997: OCV developed Advantex® Glass and Technology**
 - Boron free E-glass (higher melting power than traditional E-Glass)
 - ECR-glass (superior corrosion resistance to traditional E-glass)
 - Breakthrough in melting technology for large capacity furnaces
- **2006: OCV developed High Performance Glass Technology**
 - Combines High-Performance Glass (HPG) and melting technology
 - Production of High-Performance Glass in large capacity furnaces
- **2009: OCV developed S-glass formulation based on HPG**
 - High-Performance Glass formulation meets all international standards for S-glass
 - ASTM C-162, DIN 1259, ISO 2078, ASTM D578, and JIS R3410 standards.
 - Results in lower cost and increased capacity

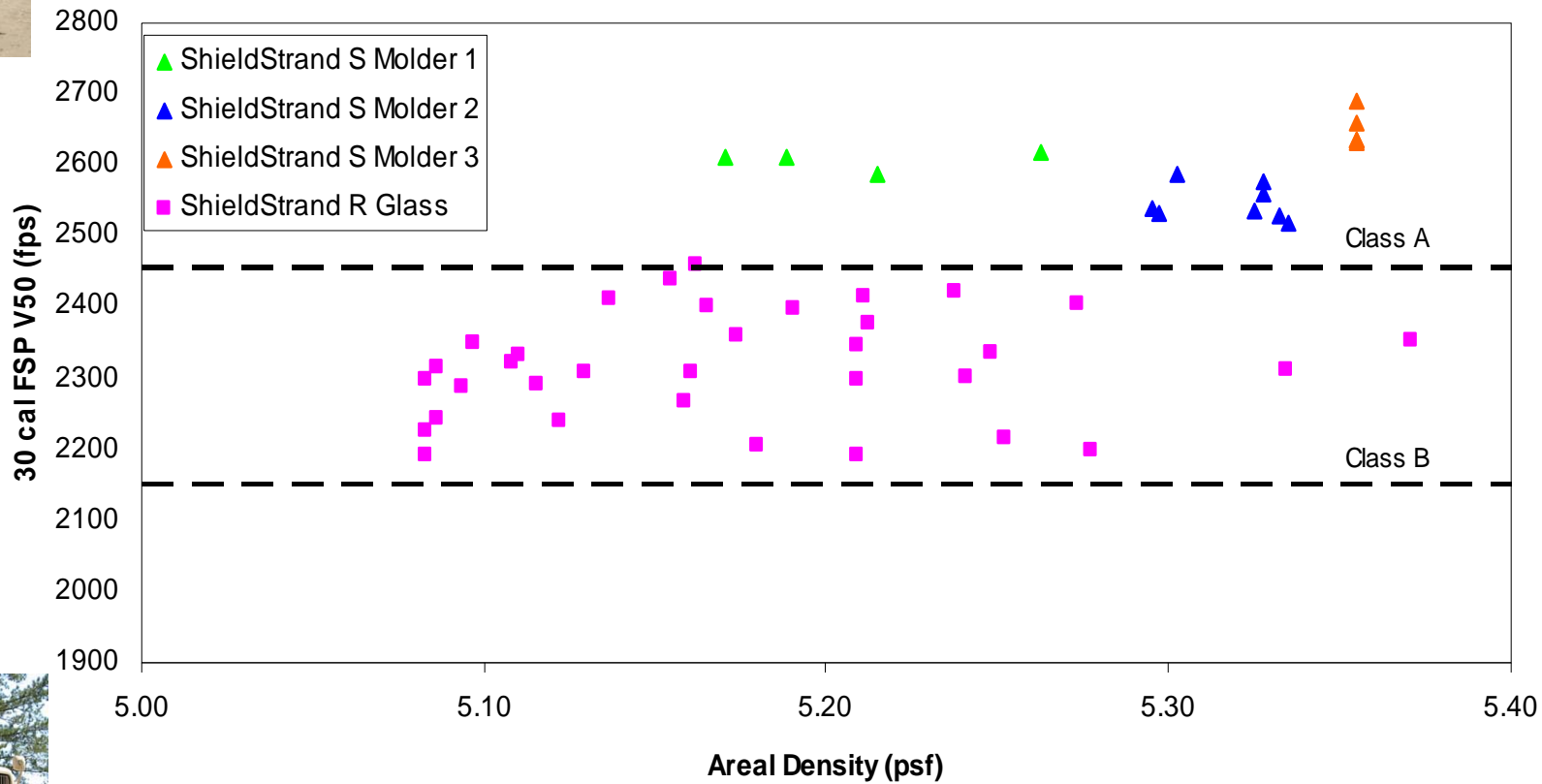


Large capacity furnaces provide a readily available supply of high performance glass fibers

ShieldStrand® Levels of Performance



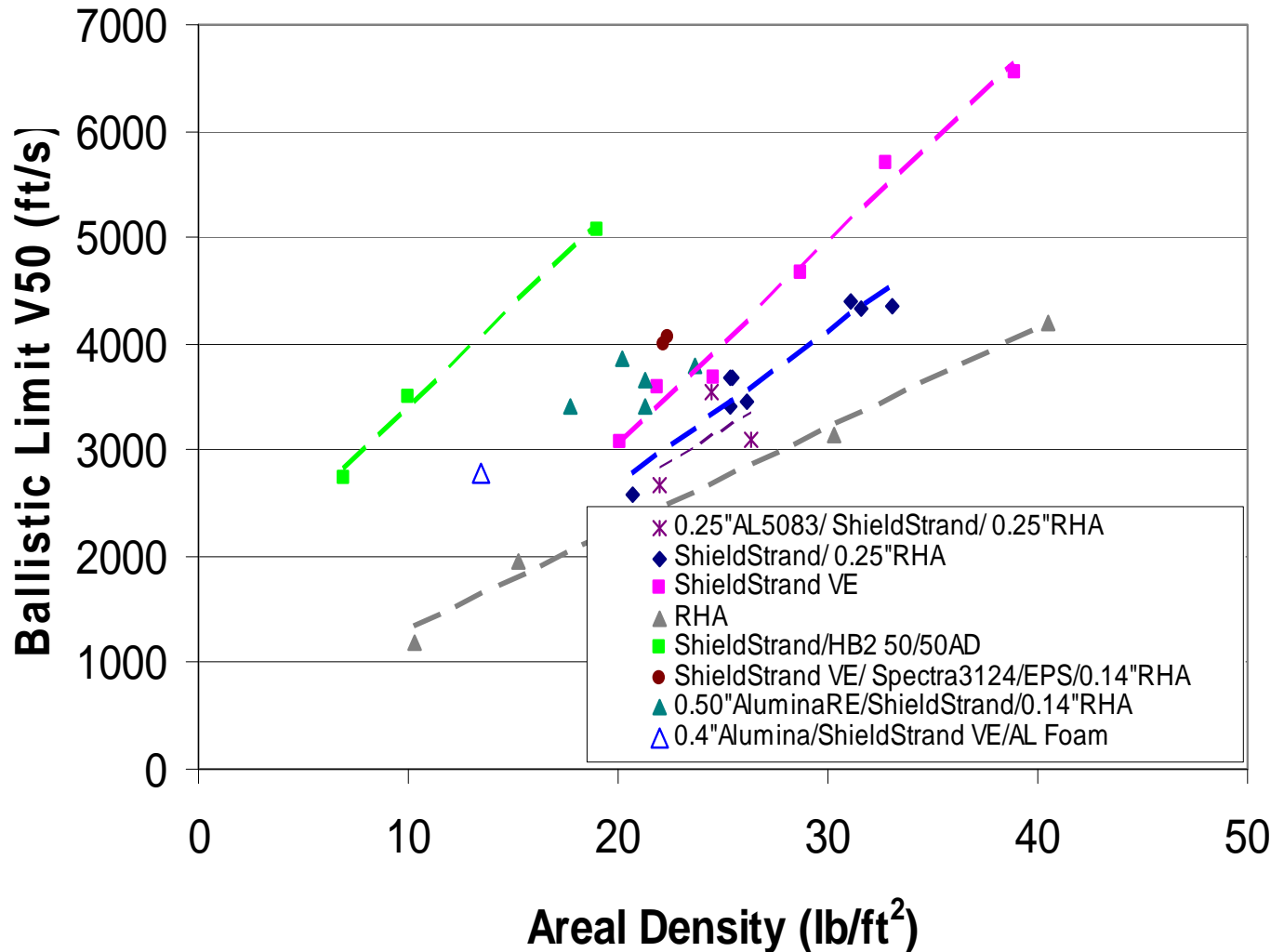
Ballistic Performance per MIL-DTL-64154B





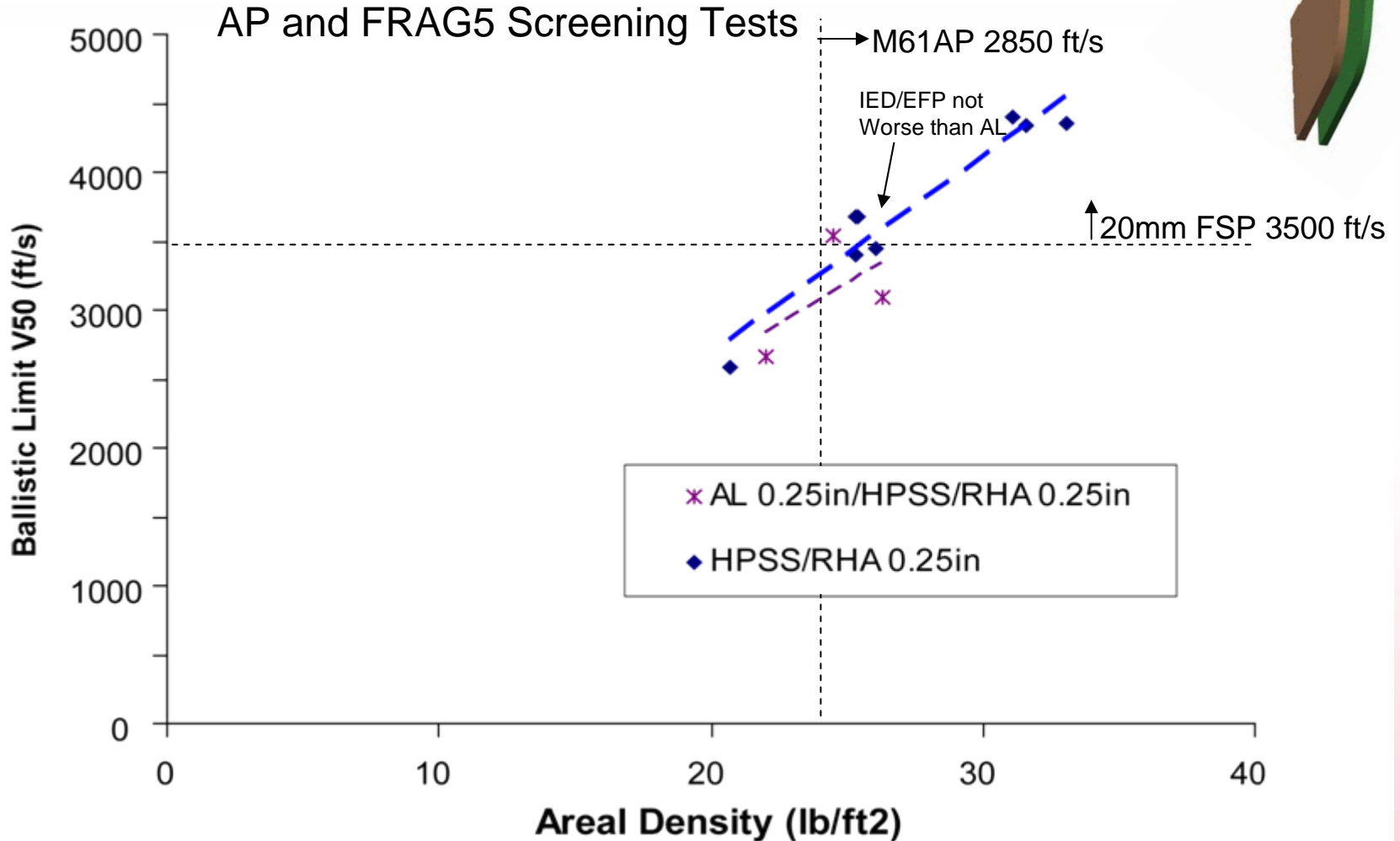
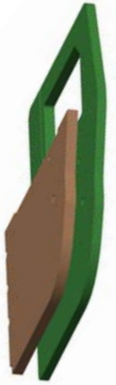
ShieldStrand® Hybrid Armor Comparison

20mm FSP MIL-STD-662 Ballistic V50 Performance





ShieldStrand[®] Armor Exterior Modules Ballistic Multi-threat Performance



Areal Density Includes 10.5 lb/ft² RHA Steel Door Skin

ShieldStrand® Phenolic Plate Properties

Elastic Constants

| | | | |
|----------------------|-------------|---------------------|-------------|
| Longitudinal Modulus | D3039, D638 | 10 ⁶ PSI | 3.5 - 4.6 |
| Transverse Modulus | D3039, D638 | 10 ⁶ PSI | 3.5 - 4.6 |
| Axial Shear Modulus | D3518 | 10 ⁶ PSI | 0.5 - 0.7 |
| Axial Comp Modulus | D695 | 10 ⁶ PSI | 5.2 - 6.7 |
| Poisson's Ratio | D3039 | 10 ⁶ PSI | 0.24 - 0.27 |

Ultimate Strains

| | | | |
|--------------------------|-------------|---|---------|
| Longitudinal Tension | D3039, D638 | % | 1.5 - 4 |
| Longitudinal Compression | D3410, D695 | % | 0.7 - 2 |
| Transverse Tension | D3039, D638 | % | 1.5 - 4 |
| Transverse Compression | D3410, D695 | % | 0.7 - 2 |
| In-Plane Shear | D3518 | % | 2 - 2.5 |

Strength Properties

| | | | |
|--------------------------|-------------|---------------------|-----------|
| Longitudinal Tension | D3039, D638 | 10 ³ PSI | 60 - 100 |
| Longitudinal Compression | D3410, D695 | 10 ³ PSI | 20 - 80 |
| Transverse Tension | D3039, D638 | 10 ³ PSI | 60 - 100 |
| Transverse Compression | D3410, D695 | 10 ³ PSI | 20 - 80 |
| Normal Compression | D695 | 10 ³ PSI | 100 - 120 |
| In-Plane Shear | D3518 | 10 ³ PSI | 17 - 30 |
| Interlaminar Shear | D2344 | 10 ³ PSI | 1.9 - 4.0 |
| Longitudinal Flexural | D790 | 10 ³ PSI | 20 - 45 |
| Longitudinal Bearing | D953 | 10 ³ PSI | 35 - 80 |

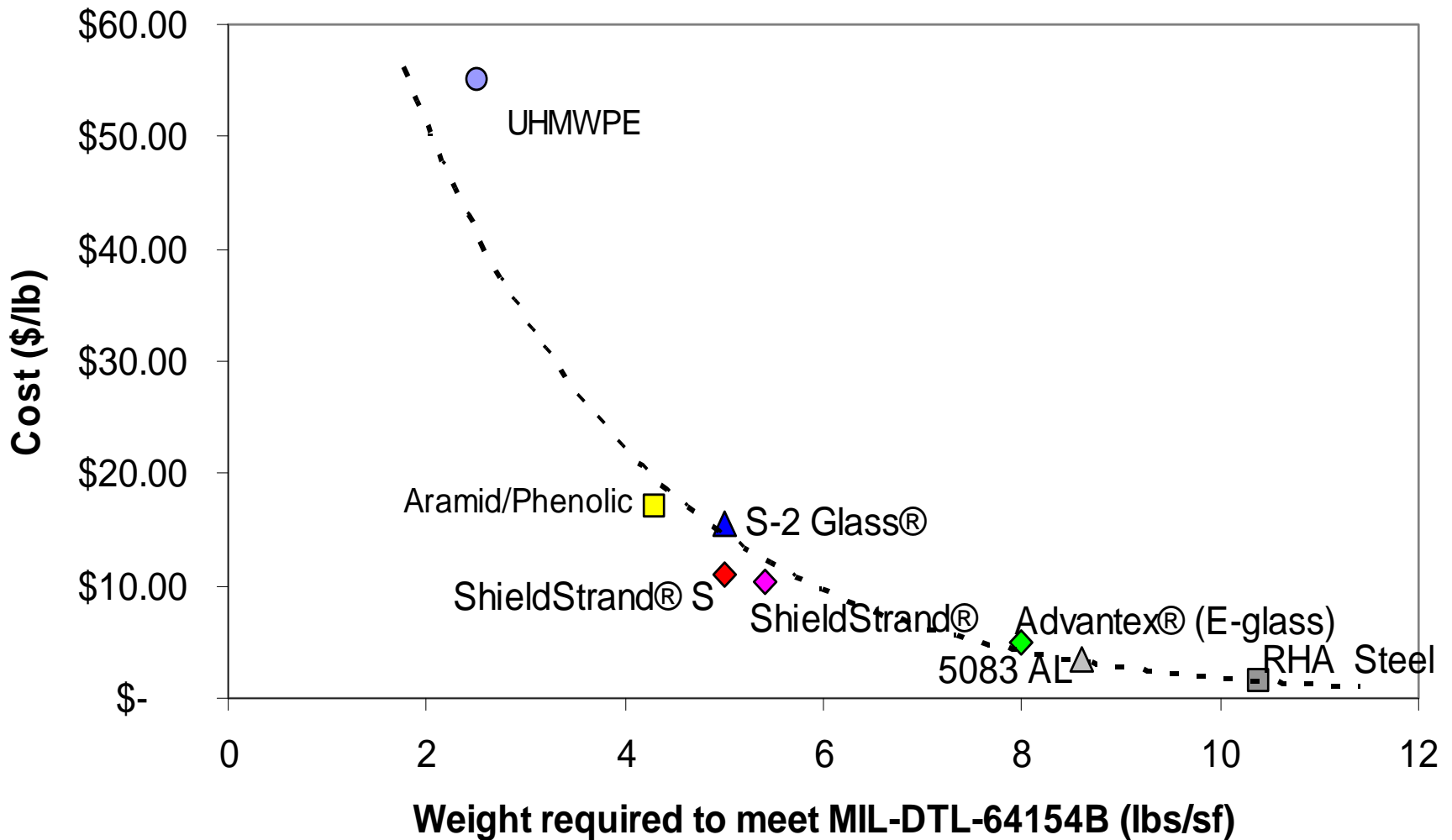
Physical Properties

| | | | |
|---------------------------------|------------|---|---------------|
| Fiber Volume | D2734 | % | 61 - 66% |
| Resin Weight | D2584 | % | 16 - 24% |
| Water Absorption | D570, D792 | % | <1.5% |
| Longitudinal Flexural, Wet Ret. | D790 | % | >70% |
| Thickness (in.) | | | 0.470 - 0.530 |
| Ply Thickness (in.) | 25 ply | | 0.019 - 0.020 |
| Areal Density (lb/sf) | 25 ply | | 4.6 - 5.4 |
| Density (lb/ci) | D792 | | 0.072 - 0.074 |
| Hardness (M scale) | D785 | | >80 |
| Thermal Transition | D4065 | | 210 - 240 |
| Flammability | UL 94 | | V0 |
| Time to Ignition @50kW/sm (s) | E1354 | | 500 - 600 |
| Total Heat Release (MJ/sm) | E1354 | | 25 - 60 |
| MAHRE (kW/sm) | E1354 | | 20 - 35 |
| FIGRA | E1354 | | 0.10 - 0.20 |

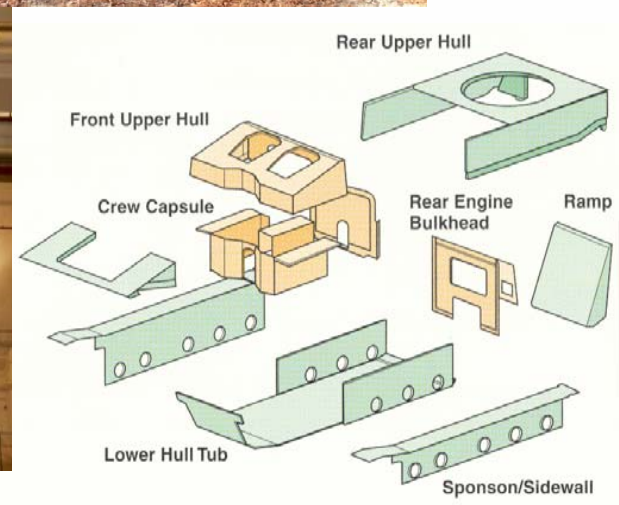




ShieldStrand[®] Enables Lightweight Composite Armor Affordability



Evolution of Composite Armor from flat plate to complex shapes for integration with steel



Compression Molded **Phenolic**

Infusion Molded **FR Epoxy Vinylester**

ShieldStrand[®] Armor Solutions for Blast and Multi-hit Fragmentation Performance



- **Effective Blast Management** – structurally good with minimal global deflection for up to 20lbs C4 or equivalent CB with 18 and 32 inch standoff.

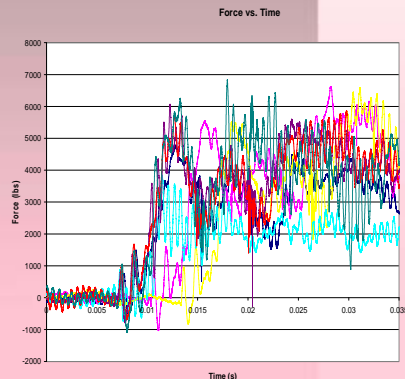
- **FR Vinylester ShieldStrand V-hull Passed 155mm mortar buried flush with standoff at 32 inch... V-hull was then subjected to full scale diesel fuel fire test and Passed.**



- **Minimal Secondary Effects Behind Armor** – V-hull vents Blast, Composite stops fragmentation, while structure absorbs Blast energy and dissipates shock.

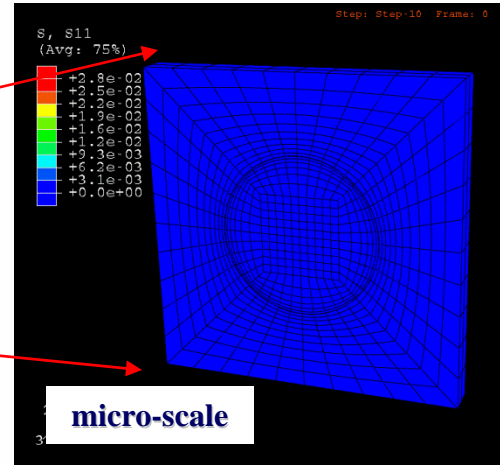
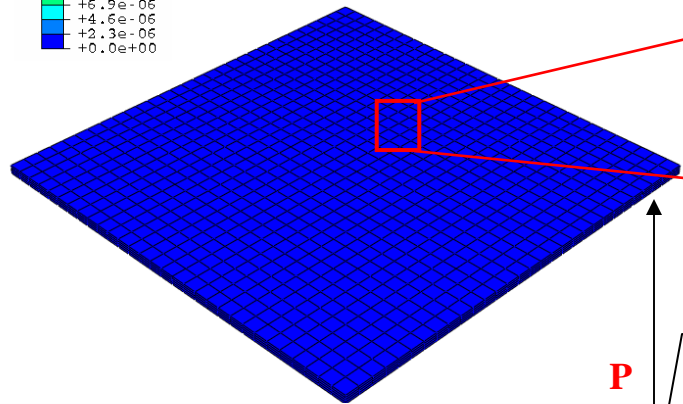
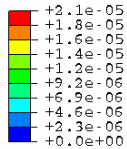
- **Blast Simulation Modeling at UDCCM, UDRI and OSU for Composite Structures with comparison to LS Dyna with Johnson Cook parameters.**

- (Ref: SwRI, BAE, AMG, ARL/ATC pending reports, DAAL04-92-C-0014, DAAL04-86-C-0079 armor reports)

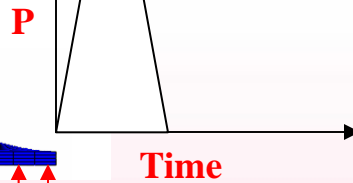


Simulation of Damage Evolution in a Clamped Plate Subjected to Blast Loading

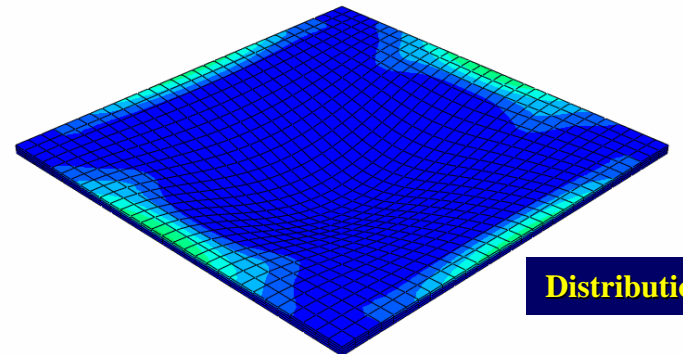
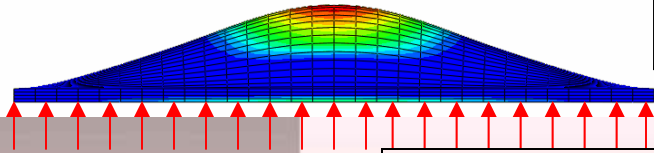
macro-scale



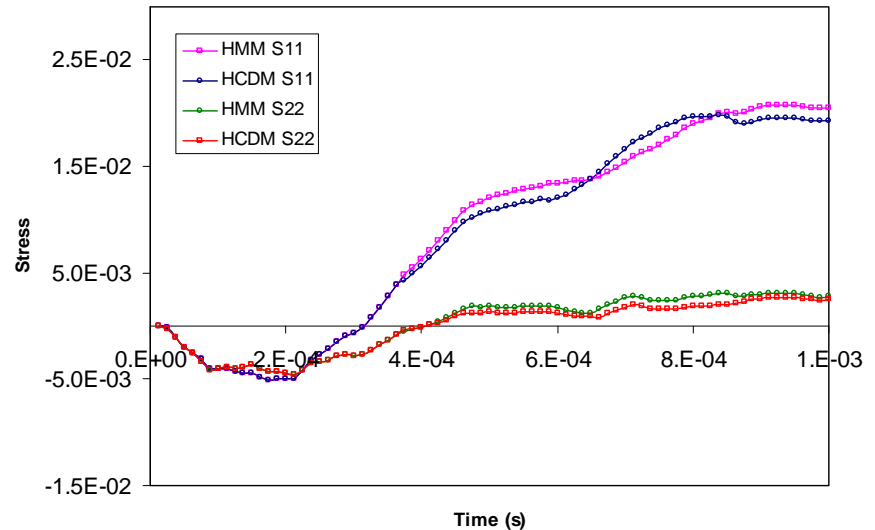
micro-scale



Blast Pressure (P)



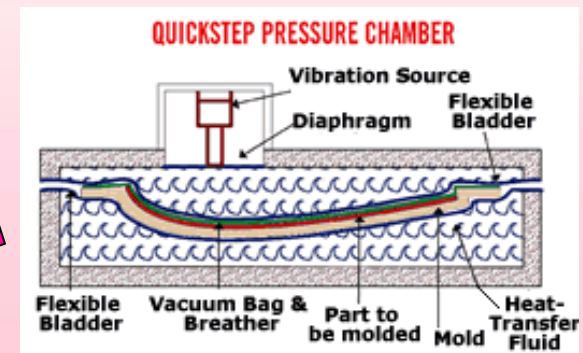
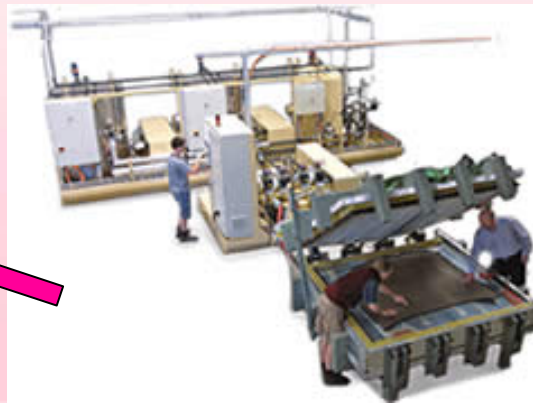
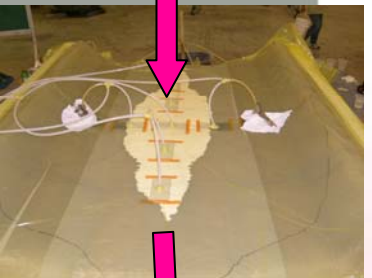
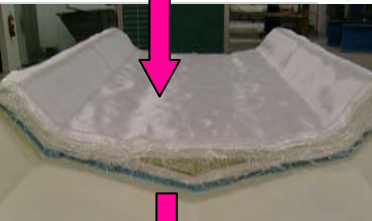
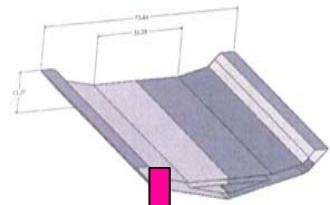
Distribution of (W_d)



Comparison of HCDM and HMM

Evaluation of ShieldStrand[®] Material and Process Parameters for Complex Shapes

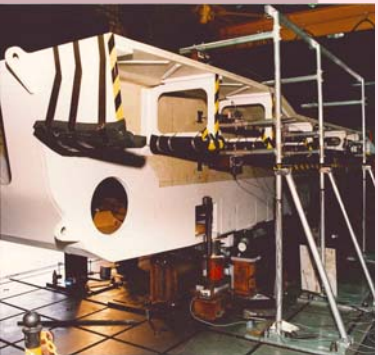
- Resin Infusion of large V-hull structure of ShieldStrand, foam core and metal inserts resulted in good structural, blast and fragmentation performance.
- FR synergists allowed excellent vinylester resin infusion process resulting in good fire performance.
- QuickStep process consolidation of phenolic prepreg in complex shapes gave 90 - 95% of the ballistic performance of compression molded phenolic.
- QuickStep demonstrated capability to produce 4 inch thick complex parts with reasonable process time.



Integrated Structural Armor

ShieldStrand® is making new armor solutions possible

- The strength of ShieldStrand® provides structure as well as protection, allowing armor to be integrated into the vehicle structure, reducing overall vehicle weight
 - Lower weight means increased vehicle payload, mobility and increased warfighter survivability
- ShieldStrand® can be molded into large complex-shaped structural parts using proven large scale composite manufacturing technologies.
- ShieldStrand® has been tested in combination with a steel or ceramic strike face to provide protection when armor piercing and multi hit capability is required or an overmatched threat exists.
- ShieldStrand® reinforcements are produced on a large scale using OCV innovative breakthrough glass fiber technology making it available and affordable. Production can support surges common in defense applications.





ShieldStrand[®] Makes Lightweight Structures with Durable Protection

Delivering Performance

- Validated MIL-DTL-64154B ballistic performance
- 40% weight savings versus aluminum for equivalent FSP protection, increasing vehicle protection, payload and mobility
- Use with a steel or ceramic strike face to provide protection when armor piercing and multi hit capability is required or an overmatched threat exists
- Meets all fire, smoke and toxicity requirements
- Provide better durability in high temperature, corrosive environments.

Enabling Possibilities

- Provides structure as well as protection, allowing armor to be integrated into the vehicle structure, reducing overall vehicle weight
- Can be molded into large complex-shaped structural parts using proven large scale composite manufacturing technologies.
- Because it is affordable, at 1/3 the cost of UHMWPE, more vehicles can be protected, increasing warfighter survivability

Readily Available

- Produced on a large scale using OCV innovative breakthrough glass fiber technology making it available and affordable
- Production can support surges common in defense applications.
- Provide an alternative supply chain that is less volatile

