US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

Lightweighting of Large Caliber Weapons – Present and Future

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Dr. Andrew Littlefield
andrew.g.littlefield.civ@mail.mil
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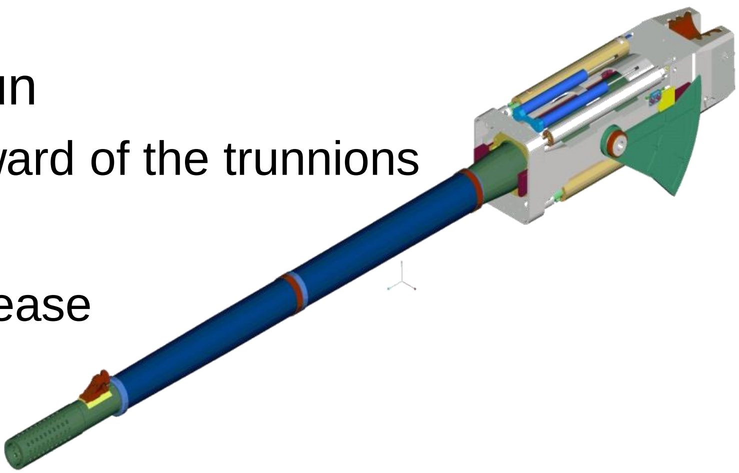
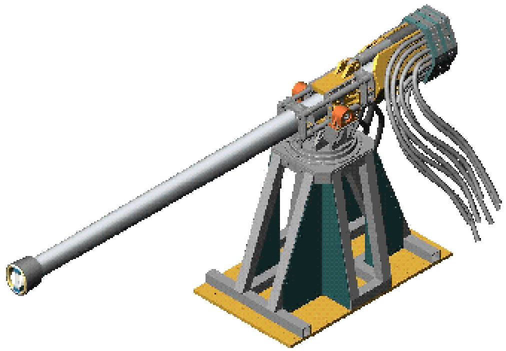
Why Use Composite Materials?

- Conventional Gun Tubes
  - Need to lighten the muzzle end of the gun
    - Center of Gravity (CG) of the tube is forward of the trunnions
  - Need to stiffen the gun
    - Desire a higher natural frequency to increase pointing accuracy
  - Need to combat dynamic strain effect
    - High projectile velocity causes strains to be amplified up to seven time static levels



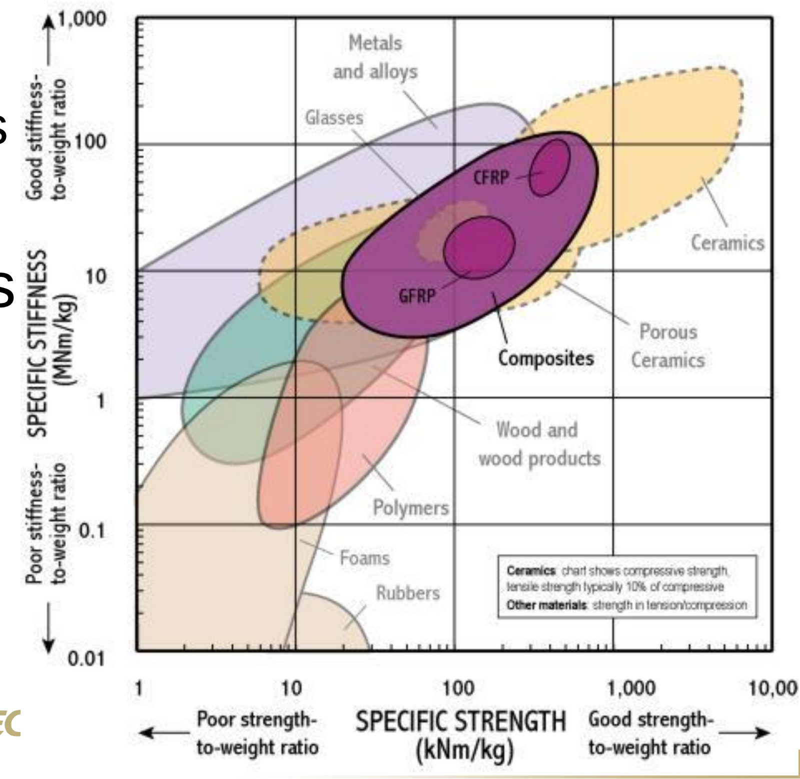
- EM Guns
  - First two above plus direct containment of firing loads without being electrically conductive



- In General
  - Lighter weight for same stiffness / strength

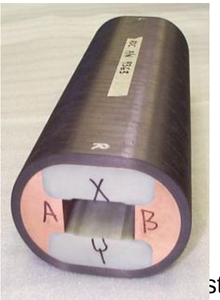
Why Use Composite Materials?

- Provides superior specific strength and specific stiffness compared to homogenous materials
- Allows for material to be placed only where needed
- Allows for unique designs using concepts such as shear coupling / extension-twist coupling
  - If you pull on the part it will twist. Has been used in experimental planes helicopters to change angle of attack
- Coefficient of Thermal Expansion is tailorable
  - CTE is 0 or negative in carbon fiber
- Possibility for high heat transfer
  - Carbon fiber can be 5 times copper



Types of Composite Materials

- Material Types
  - Polymer Matrix Composites (PMC)
    - Graphite, Kevlar, Fiberglass
    - Thermoset, Thermoplastic, Pre-Ceramic Polymers
  - Ceramic Matrix Composites (CMC)
    - C/SiC, SiC/Al_2O_3, SiC/SiC
  - Metal Matrix Composites (MMC)
    - Al/SiC, Ti/SiC, Mg/SiC
  - Carbon/Carbon (C/C)
    - C/C, C/C/SiC

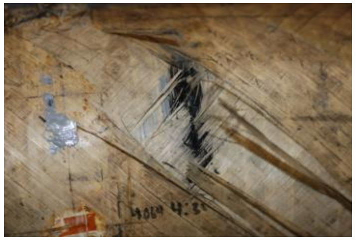


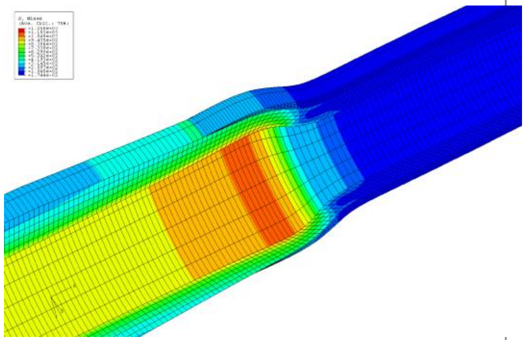
Previous Work in Composite Gun Tubes

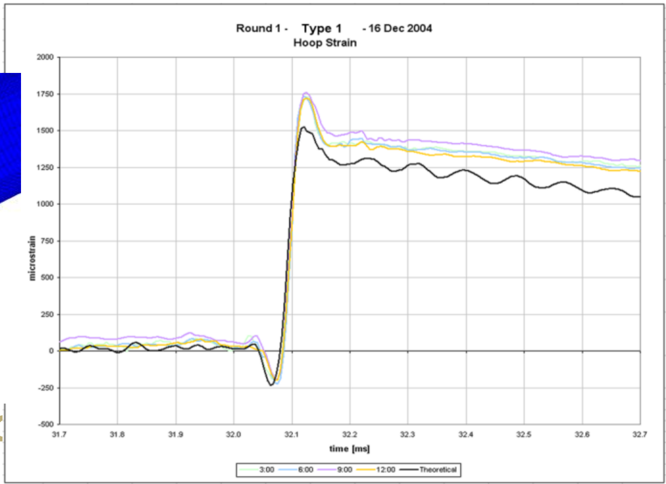
- 40 years of Benét expertise in composite cannon development, manufacture, and testing.
  - Organic Fiberglass 105mm (No Pre-stress)
  - Titanium Jacketed 120mm (Swage Pre-stress)
  - Metal Matrix Composite 120mm (Swage Pre-stress)
  - Organic Composite 120mm (Swage Pre-stress)
  - Organic Thermoset 105mm MRAAS (Lay-up Tailoring – No Pre-stress)
  - Electromagnetic Railgun Tubes
  - M256 Bore Evacuator
  - Paladin Ballistic Shield
  - LOS/BLOS ATD Thermoplastic Wrapped Tube

LOS/BLOS ATD & XM360 SDD

- 120mm Organic Thermoplastic Overwrap
  - 113.4 kg (250 lbs) steel removed
  - 20.4 kg (45 lbs) IM7/PEEK applied
  - 72 layers, hoop to axial ratio of 2:1
- 14 Tubes Manufactured at Benet
  - Cooled and wound under tension – 60 lbs
  - NDE conducted before and after firing
- Fired between 2004 and 2007 at APG
  - Some tubes saw over 250 rounds
- Two tubes subjected to Fatigue, Safe Maximum Pressure and Damage Testing
  - Tubes behaved as predicted
  - Damaged tube cycled 100 times without failure

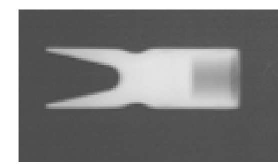


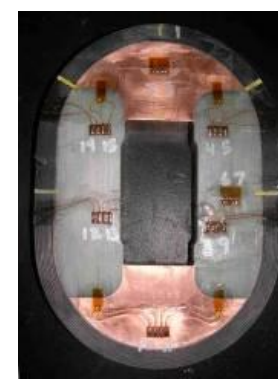




Electromagnetic Railgun

- Composite Jacket
  - Hoop to axial ratio of 2:1
  - S2 / PEEK for insulation
  - IM7/PEEK applied under 250 lbs tension
- C18000 Chromium Copper Rails
- Nextel 610 2D / 3D weave Insulators
- 2m fired in July 2007 at Yuma Proving Grounds
  - First railgun fired fully cantilevered
  - First tactical type railgun in two decades
- 4m gun fired in 2008
  - 720g projectile at 2.07 km/s

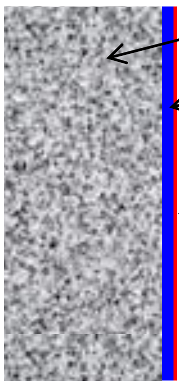




Reengineering 81mm Mortar System - Tube

- Goal is to reduce system weight from ~90 lbs to ~50 lbs by applying composites to tube and baseplate while maintaining performance
- Flame temperatures of 3400K and high firing rate limit ability to use standard PMC's
- Tube Options - Metal matrix, ablatives, pre-ceramic polymers, and carbon-carbon

MMC Option

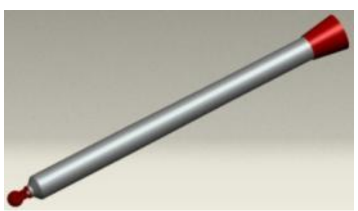


MetPreg MMC (0.20-0.25" thick)

Ceramic insulation layer (YSZ, 0.01-0.02")

Yitra Stabilized Zarconia

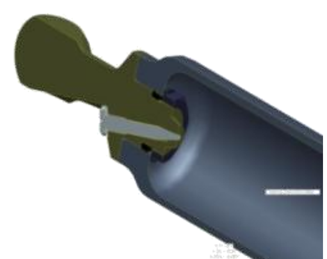
Thermal shock resistant layer (MCrAlY, 0.005-0.010")
M = Nickel or Cobalt (or combination)
Chromium, Aluminum, Yitrium

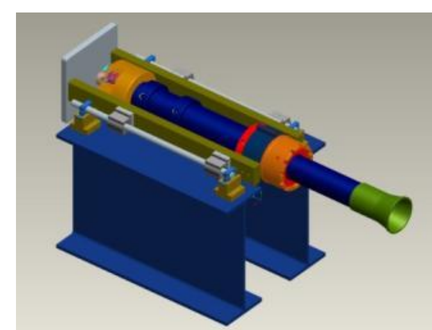


Carbon/Carbon Tube

- Working with AFRL at Edwards AFB to develop a C/C/SiC tube
- Initial sample formulations have been subjected to Pulse Laser Heating and some VES testing
- Liner being fabricated for range

- Tube samples passed simulated heating test
  - MMC/TBC with and without Inconel Liner
    - New program starting this Summer
  - PyroKarb /TBC with and without Inconel Liner
    - Continued under FTAS effort



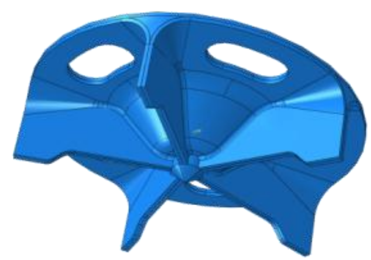


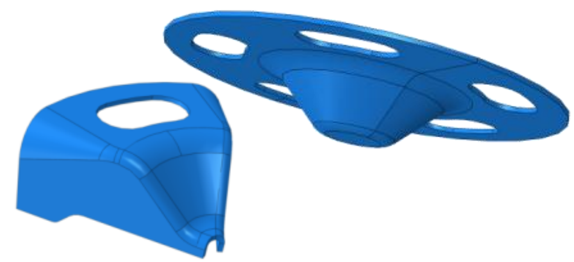
Reengineering 81mm Mortar System - Baseplate

- Goal is to reduce system weight from ~90 lbs to ~50 lbs by applying composites to tube and baseplate while maintaining performance
- Flame temperatures of 3400K and high firing rate limit ability to use standard PMC's
- Previous composite baseplate efforts failed at leg / plate joint
- Baseplate Options – Modular, 3D Weave
  - Target weight is 15 lbs - Current 24 to 30 lbs

Modular Option

- Designed as a series of pie pieces
- Each piece contains half a leg and part of the top plate
- Top plate covers all five pieces
- Projected to weigh 15 – 18 lbs





3D Weave Option

- Uses 3D weave in top plate and legs
- Two weaving vendors: TEAM & 3TEX/Saertex
- Univ of Delaware CCM completing VARTM at present
- Legs: integral with inserts (TEAM) or stitched (3Tex)
- First article weighs 12.7 lbs without socket hardware
- Should be test fired this Summer

155mm M284 Lightweight Bore Evacuator

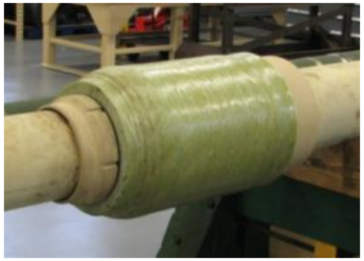
Design Goals:

- Reduce Maintenance Burden
  - Make it easier to Remove / Install Bore Evacuator

Design Approach :

- Reduce Component Weight
  - Current weight 200+ lbs, new weight, 78lbs
- Use Composite Bore Evacuator Fabrication Processes developed for the 120mm M256 Cannon (M1A1 / M1A2 Abrams Tank)
- Find alternative material to sole source Cytec material used on M256 evacuator
- Conduct Laboratory Strength of Design (Burst) Testing
- Conduct Live Fire Testing
  - Evaluate both bore evacuator performance & Ease of Maintenance

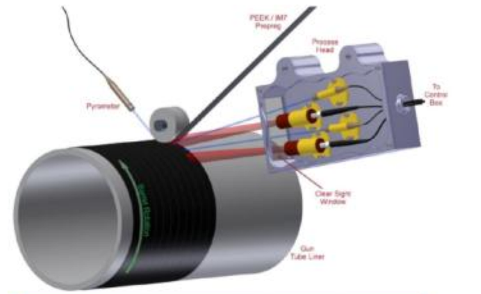
Going into Production Summer 2015

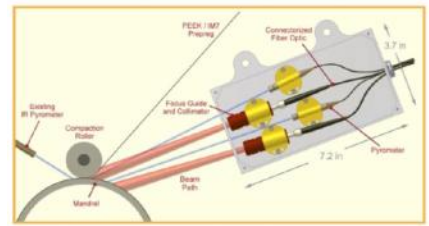


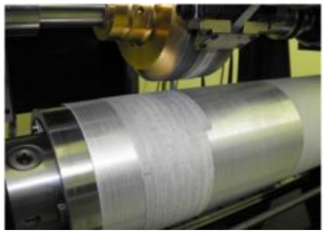
<u>New Design will be Functionally Identical to Current Configuration</u>

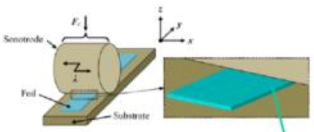
SBIR & STTR - MMC Tape Placement

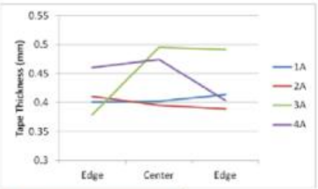
- Phase II SBIR
  - "MMC Reinforced Gun Barrels" – Automated Dynamics - Contract # W15QKN-10-C-0115
    - Goal was to develop method for tape placing MMC
    - Inconsistencies in raw material were not solved before program ended, but issues are known
  - "Directed Heating System for High Speed Manufacturing of Thermoplastic Composites" – Creare Inc. - Contract # W15QKN-11-C-0137
    - Using laser heating instead of hot gas torches for thermal energy
    - Currently making test rings at 10.6 in/s, our typical winding speed is 4.5 in/s
- Phase I STTR – "Manufacturing Process Optimization of Ultrasonic Bonding of Metallic Composites"
  - Objective is to develop and validate multiscale models of ultrasonic bonding during tape placement of metallic composite structures
    - Automated Dynamics - Contract # W15QKN-12-C-0153
      - High powered VHP-UAM machine at Edison Welding Institute showing improved properties in manufactured samples
    - Applied Optimization, Inc. – Contract # W15QKN-12-P-0053
      - Analytical modeling of dissipated energy at the material interface is helping predict bond quality
    - Touchstone Research Laboratory, Ltd. – Contract # W15QKN-12-C-0157
      - Numerical modeling of acoustic softening along with research into the tape geometry will lead to improvement in results and more consistency in the process.
- Phase II STTR – "Optimized Process for Ultrasonic Consolidation of Metallic Composites" - Awarded Jun 2014

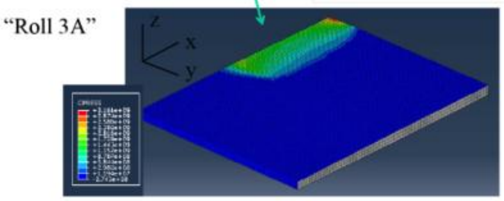






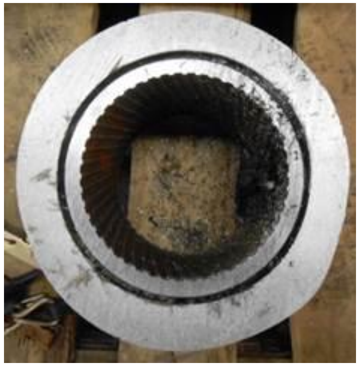


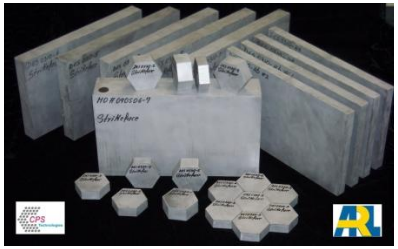


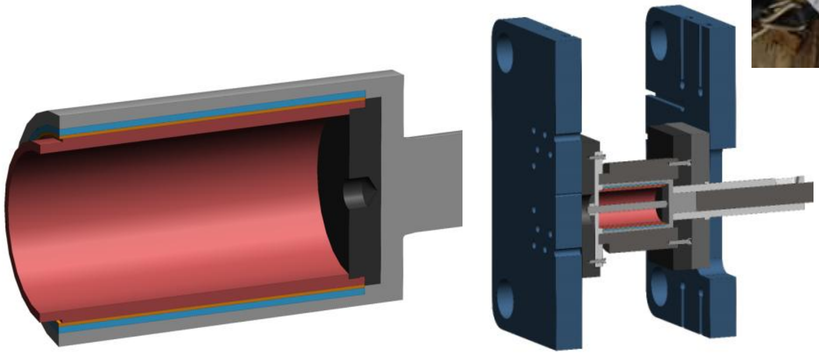


MMC for ERCA

- Cast MMC jacket in-situ on the end of the ERCA tube
  - Ceramic (Nextel 610 – Al_2O_3) fiber in an aluminum matrix
  - ARL developed a casting process for producing MMC armor
- Working with ARL primes to adapt the process to gun tubes
  - Need to consider temperature of the substrate during casting
  - How to cast over only a section the gun barrel
- CPS technologies cast first piece in Jan but failed
- REL is getting ready to cast first piece

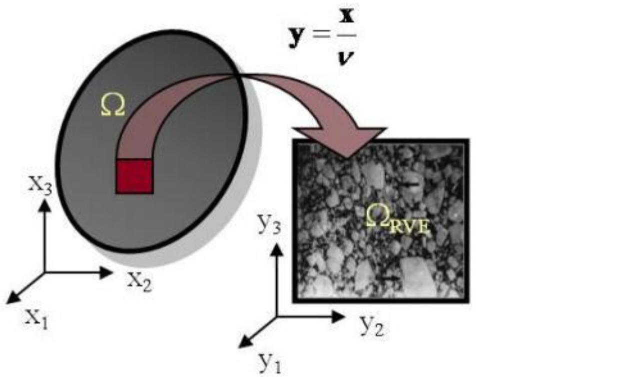






Multiscale Modeling of Composites

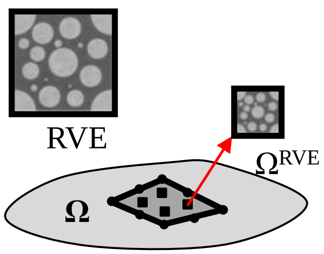
- Developing advanced modeling methods, based on using complex functions, called “enrichment functions”, to capture the effects of the micro-structure.



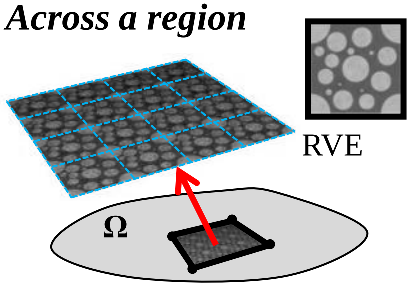
$$u_i^\nu(\mathbf{x},\mathbf{y}) = u_i^0(\mathbf{x}) + \nu\varepsilon^0_{jmx}(\mathbf{x})H^S_{jmi}(\mathbf{y}) + \nu\theta^0(\mathbf{x})H^\theta_j(\mathbf{y})$$

- The enrichment functions are generated at either:

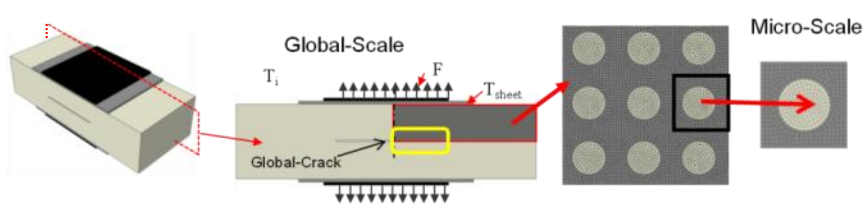
Integration points

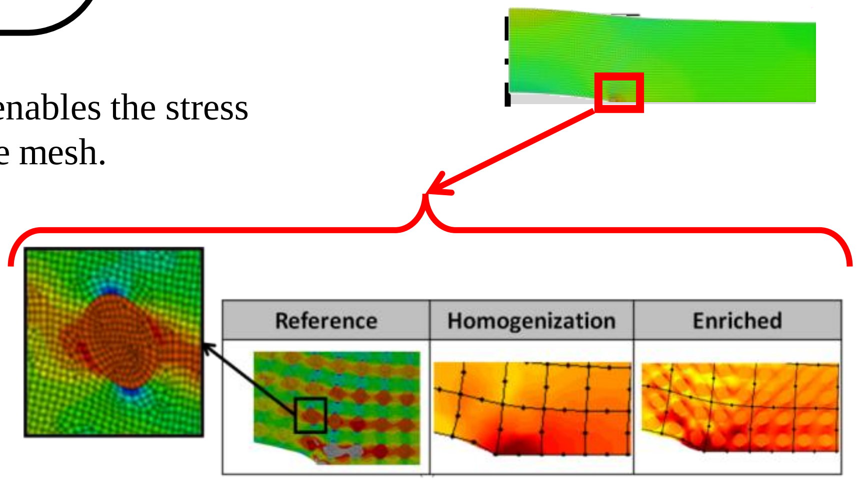


Across a region



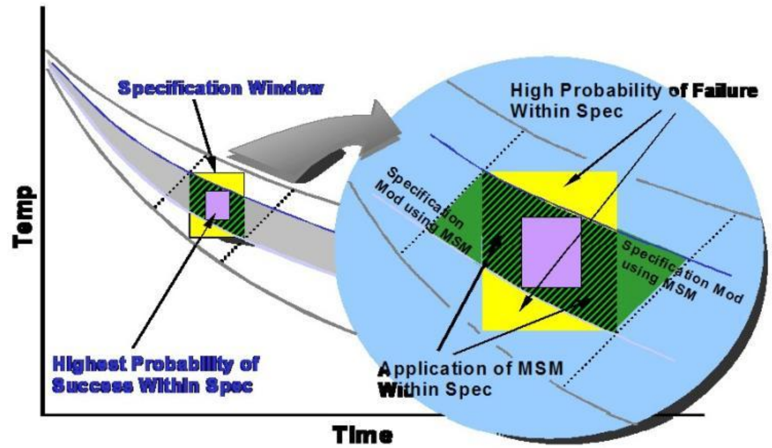
- The results demonstrate that using the enrichment technique enables the stress fields on the micro-structure to be captured with a very course mesh.



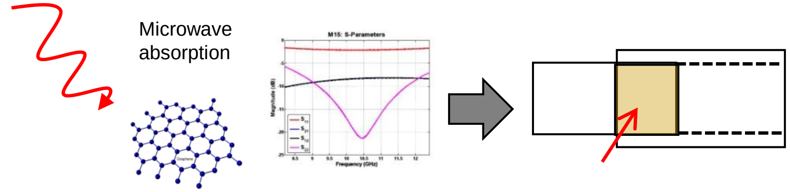


Basic Research Efforts

- Cure State Modeling
  - Prepreg has a set shelf life
    - Supplier sets it to be safe
    - Based off a specific cure cycle
  - Cure cycle can instead be defined by viscoelastic properties
    - Rheometer used to drive autoclave
  - Will result in much longer shelf lives



- Graphene Doped Thermoplastic
  - Graphene heats up when exposed to microwaves
  - Allows for reusable adhesives and elimination of threads



Reusable adhesive
Thermoplastic-graphene joint

Elimination of wasteful
Threaded joints

- Doping polymers and metals with nanoparticles to improve strength and thermal stability

Conclusions

- Tank Cannons
  - Can barely handle firing all rounds on board
  - Need a higher Tg by about 100F
- Howitzers
  - Steady state temperatures supposed to be <630F
  - Need process for incorporating MMC
  - Could also make other structures such trails / muzzle brakes
- 81mm Mortar Tube
  - Most aggressive environment
  - Currently trying ablatives, MMC, C/C, Pre-ceramic polymers
- Mortar Baseplate
  - Manufacturing methods need to be tested
  - Modeling is difficult due to varying ground conditions
- Bore Evacuator
  - Using existing manufacturing methods for rapid deployment
  - Loading and stress issues to be worked out
- ATO MOUT Launcher
  - Single shot use simplifies thermal issues
  - Need accurate pressure travel information to design properly
- Modeling and nano efforts will lead to new applications / designs

Technology Available Timeline

Technology / Application — Ready for Use

- Standard thermoset materials
  - Modular mortar baseplate
- Thermoplastic Tape Placement with High Tension and Integral Cooling
  - XM360, EM Gun, MOUT

Now

- 3D Weave with VARTM / RTM
  - 3D Woven mortar baseplate
- MMC Wet Winding
  - Mortar Tube
- High Temperature Geopolymer / Preceramic Polymer
  - Mortar Tube

1 – 3 yrs

- Low Cost Carbon/Carbon/Sic
  - Mortar Tube
- Cure Cycle Envelope Definition / Shelf Life Extension
- Multiscale Modeling
- MMC Casting
  - Howitzer

3 - 5 yrs

- MMC Tape Placement
  - Howitzer
- Composites filled with nanoparticles for extreme temperatures
- Mettalic nanocomposites

5+ yrs

Contact Info

Andrew Littlefield
518-266-3972
andrew.g.littlefield.civ@mail.mil

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