Lightweighting of Large Caliber Weapons – Present and Future

Dr. Andrew Littlefield
andrew.g.littlefield.civ@mail.mil
21 Apr 2015

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited
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 times 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/Al₂O₃, SiC/SiC
  - **Metal Matrix Composites (MMC)**
    - Al/SiC, Ti/SiC, Mg/SiC
  - **Carbon/Carbon (C/C)**
    - C/C, C/C/SiC
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
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
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, Yttrium

**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

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.
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
Design Goals:
• Reduce Maintenance Burden
  o Make it easier to Remove / Install Bore Evacuator

Design Approach:
• Reduce Component Weight
  o 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
  o Evaluate both bore evacuator performance & Ease of Maintenance

Going into Production
Summer 2015

New Design will be Functionally Identical to Current Configuration
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

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited
Cast MMC jacket in-situ on the end of the ERCA tube
  – Ceramic (Nextel 610 – Al₂O₃) 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
Developing advanced modeling methods, based on using complex functions, called “enrichment functions”, to capture the effects of the micro-structure.

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 coarse 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

- **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 / Application

- Standard thermoset materials
  - Modular mortar baseplate
- Thermoplastic Tape Placement with High Tension and Integral Cooling
  - XM360, EM Gun, MOUT
- 3D Weave with VARTM / RTM
  - 3D Woven mortar baseplate
- MMC Wet Winding
  - Mortar Tube
- High Temperature Geopolymer / Preceramic Polymer
  - Mortar Tube
- Low Cost Carbon/Carbon/Sic
  - Mortar Tube
- Cure Cycle Envelope Definition / Shelf Life Extension
- Multiscale Modeling
- MMC Casting
  - Howitzer
- MMC Tape Placement
  - Howitzer
- Composites filled with nanoparticles for extreme temperatures
- Mettalic nanocomposites

Ready for Use

Now

1 – 3 yrs

3 - 5 yrs

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

US Army RDECOM-ARDEC Benét Laboratories