Contact info

- Larry Burton
- 410-306-0767
- U.S. Army Research Laboratory
- coach@arl.army.mil

Ceramic Gun Barrel Technologies

Larry Burton
Jeff Swab
Rob Carter
Ryan Emerson

U.S. Army Research Laboratory
Weapons & Materials Research Directorate

Ceramic Materials

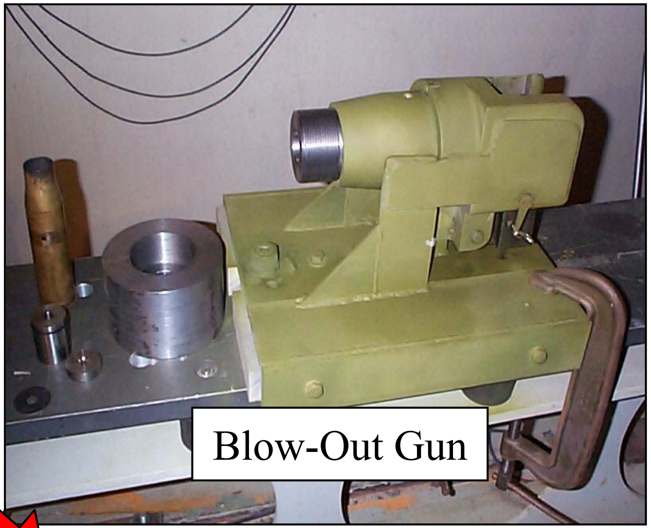
Material	Vendor	Vendor Code	ARL Code	Density (g/cm^3)
Al_2O_3	CoorsTek	AD995	ALOX	3.8
ZrO_2	CoorsTek	Ce-TZP	ZRO2	6.1
SiC	Saint-Gobain	Enhanced Hexoloy SA	SCEH	3.1
SiC	Saint-Gobain	LPS Hexoloy SA	SCLH	3.1
SiC	Ceradyne	146-5S	SC46	3.1
Si_3N_4	Ceradyne	147-31N	SN47	3.2
Si_3N_4	Kyocera	SN235P	SN5P	3.2
SiAlON	Kennametal	TK4	STK4	3.4

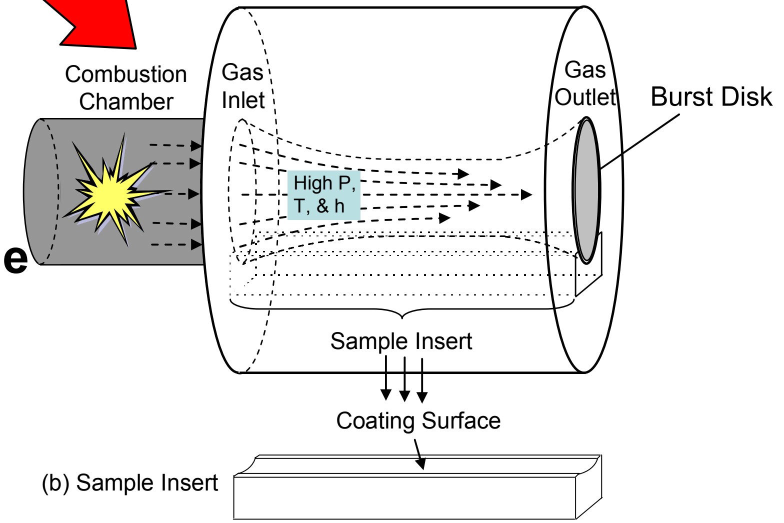
- **Eight candidate materials were chosen from commercial vendors**
  - **All materials are off-the-shelf technologies**
  - **No material development was planned for this ATO**
- **Extensive test matrix developed to characterize the mechanical and thermal properties of each material**

Erosion and Damage Tests

Different simulators used to test the erosion resistance of ceramics

- Blow-out Gun – ARL
  - Extreme condition erosion test
- Closed Bomb Test – ARL
  - Examine propellant gas-ceramic chemical interactions
- Vented Erosion Simulator (VES) Test– Benet Laboratories
  - Simulates the IB conditions seen in a 120mm system
- Pulsed Laser Heating Test – Benet Laboratories
  - Capable of inducing thermal shock damage similar to that created during an IB event

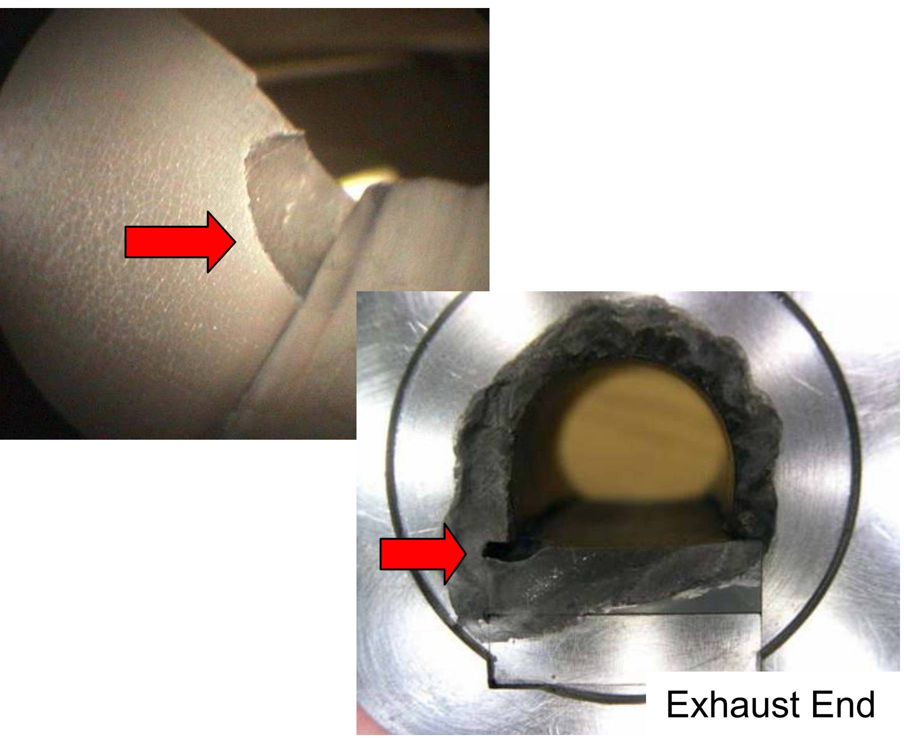




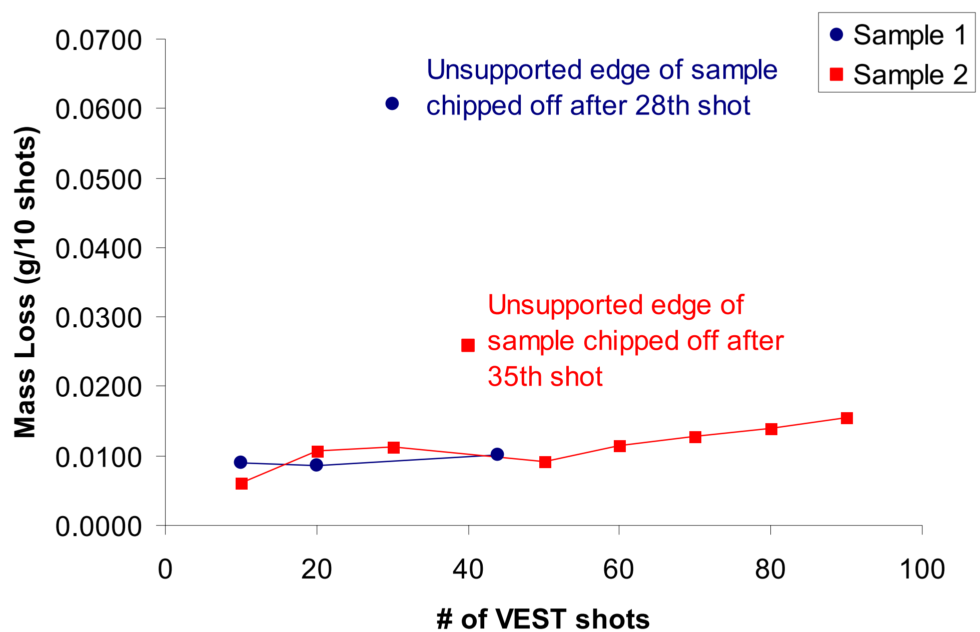
VENTED EROSION SIMULATOR

Simulates erosive environment of a Large Caliber tank gun

- SN5P scheduled to be exposed to 100 rounds
- Mass loss determined after every 10 rounds
- Terminated after 44 and 94 rounds due to potential damage to the VES fixtures *NOT because of damage to the ceramic*



Exhaust End



Erosion Summary

- Si_3N_4 and SiAlON performed well in all tests
  - Lower mass loss per shot than gun steels
  - Exhibited some fracturing
    - Not unexpected since all fixtures were originally designed for steel samples with no modifications made for the ceramic samples
    - Damaged VES samples did not exhibit an accelerating erosion rate
- SiC and Al_2O_3 showed significant mass loss due to fracture
- ZrO_2 exhibited extensive damage & accelerating mass loss

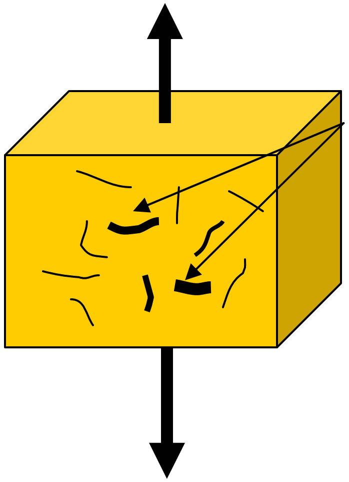
Low erosion rates make ceramics attractive as gun barrel materials

However, ceramics are hindered by brittle facture, low fracture toughness, and highly variable tensile strength

- Need new modeling and failure prediction approaches to design a ceramic lined barrel.
- Require methods for imparting high compressive prestress

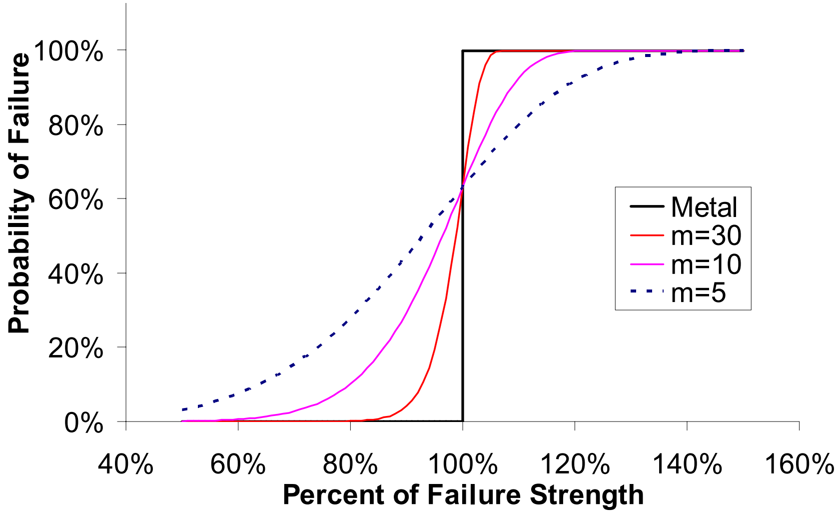
Modeling Brittle Failure

- Ceramics can support tensile load, but are subject to large scatter in the observed strength
- Brittle material design requires a change from the *deterministic methods* used in metals to a *probabilistic approach*:
  - Failure initiated at random flaw sites scattered throughout the material
  - Failure strength for each sample determined by the stress exceeding the strength at a critical flaw
- Weibull statistics are used incorporate this information into design parameters



$$P_f = 1 - e^{-\int \left(\frac{\sigma}{\sigma_o}\right)^m dV}$$

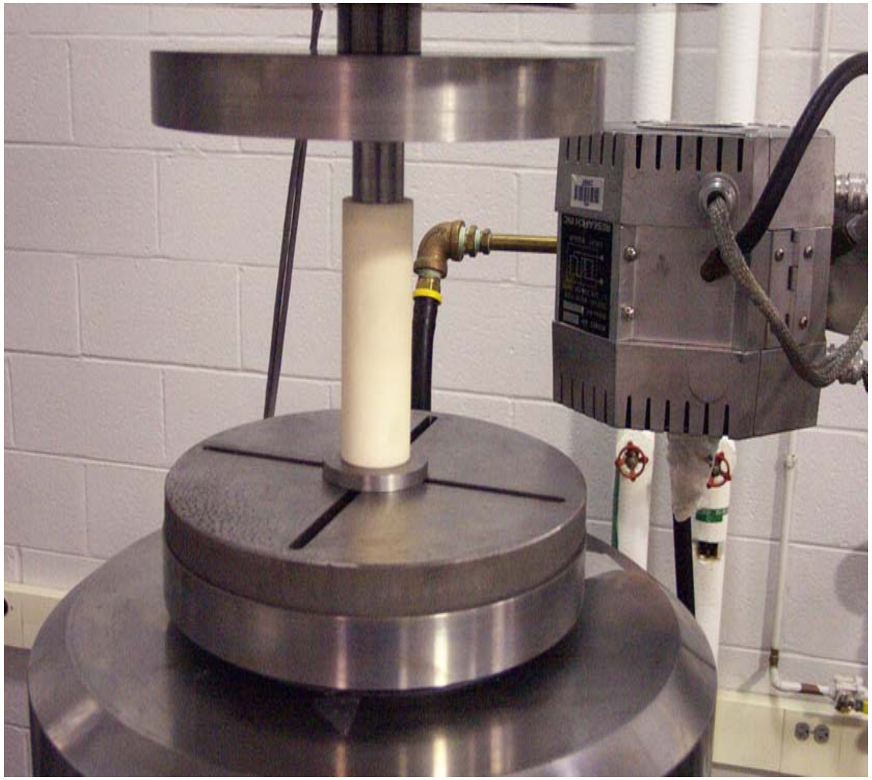
P_f = Weibull Probability of Failure
σ = Applied Stress
σ_o = Characteristic Strength
m = Weibull Modulus



Internal Pressure Testing

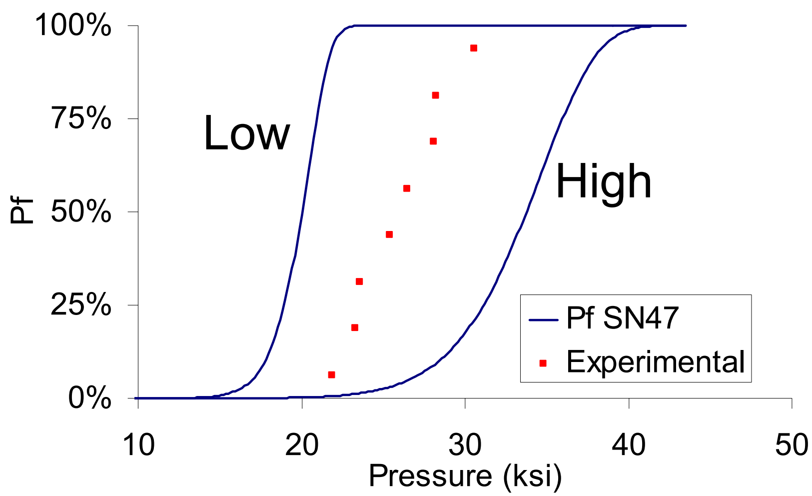
Experimental Data and Model Predictions

- **Ceramic tubes tested by internal pressurization**
- **Model predictions based on measurements for the strength of different flaw populations**
  - **Uniaxial tension to determine the volumetric flaws**
  - **C-ring tests the outer surface flaws**
- **A lack of data on the inner surface flaws -** ***they are presumed to be identical to the outer surface flaws***
  - **This leads to two different predictions for the following plots**
    - **High - the predicted strength for volumetric flaws only**
    - **Low - the predicted strength for volumetric and surface flaws**

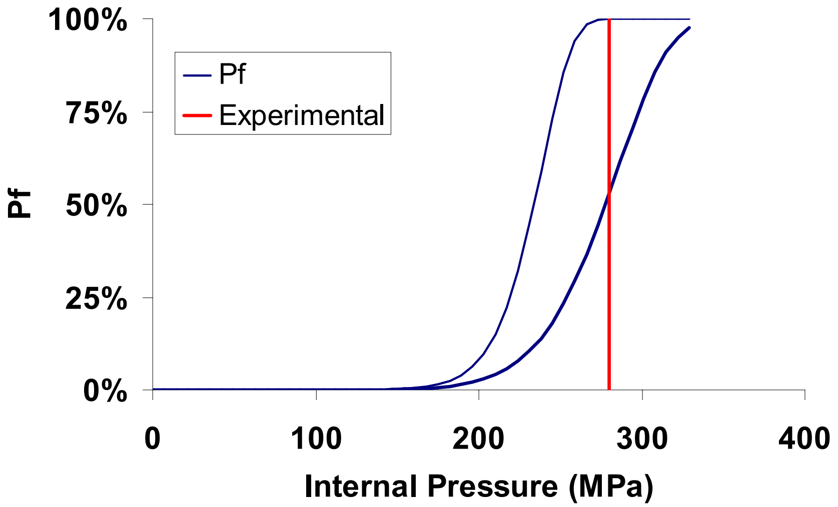


Model Predictions

SN47 Unsheathed



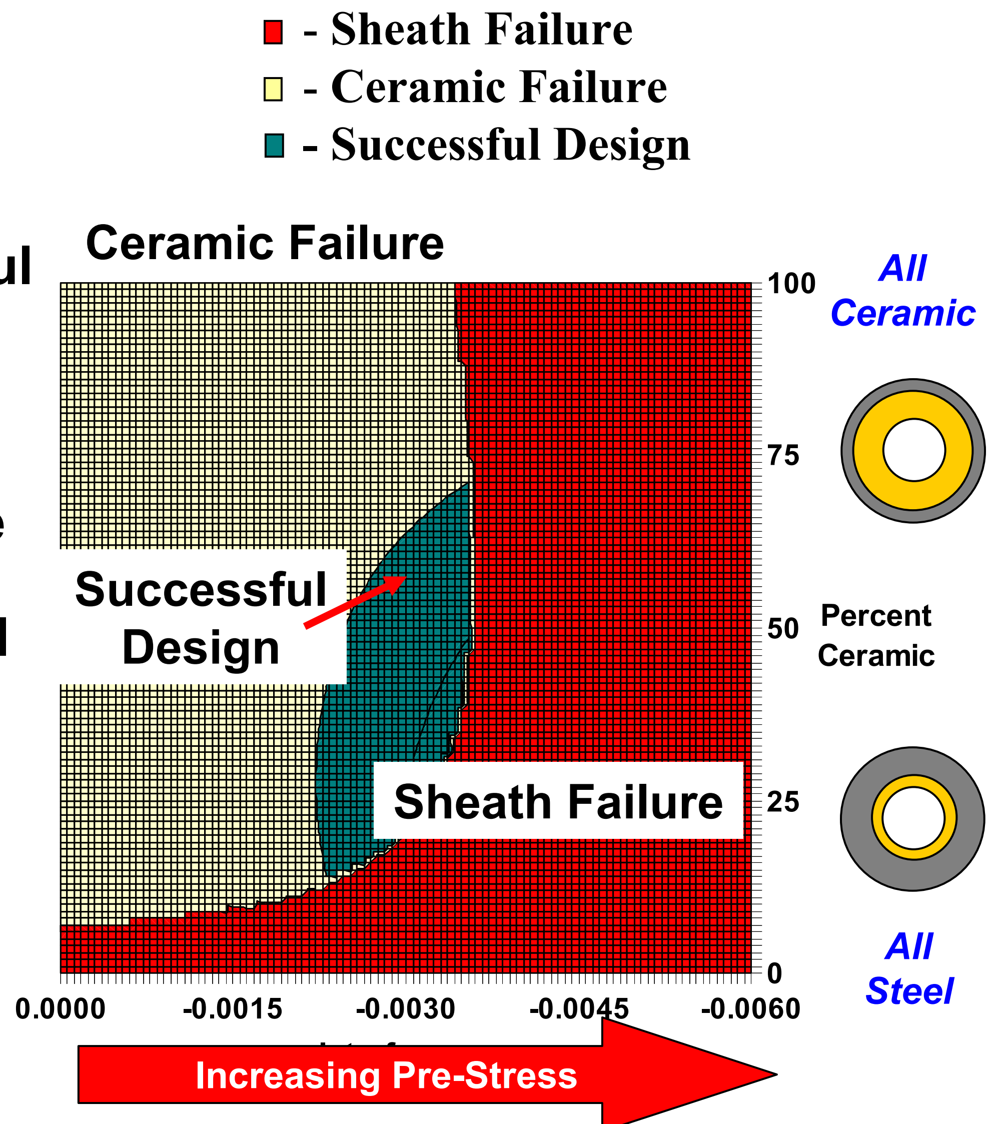
SN47 + Composite Sheath



- **Calculated failure pressure ranges bracket the experimental values**
- **The model predicts ranges for both unsheathed and sheathed tubes**

Failure Surface Plots

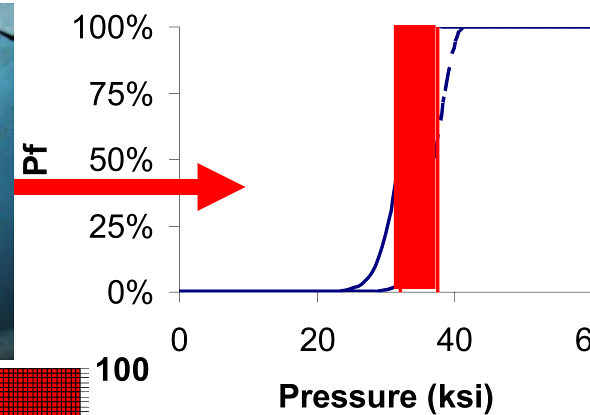
- Experimental data supports model predictions
- The next step is to apply the model to search for successful designs for different gun/cannon tubes
- Failure surface plots illustrate the effects of varying ceramic thickness and pre-stress level for a pressurized tube
- Provides quick approach for visualizing 10,000 different design concepts

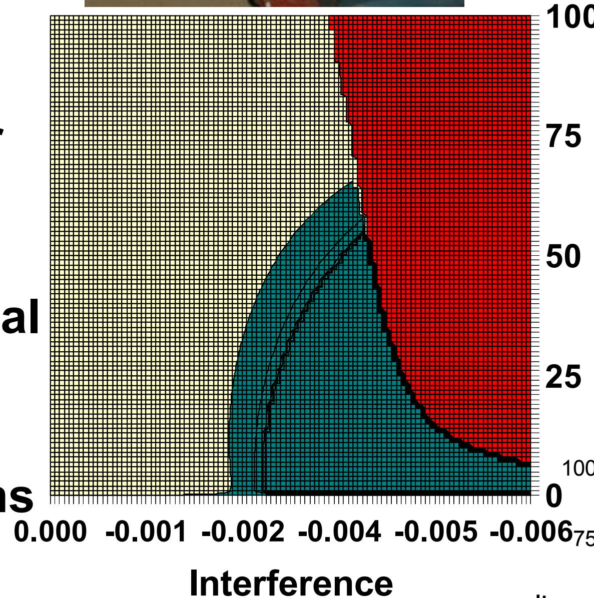


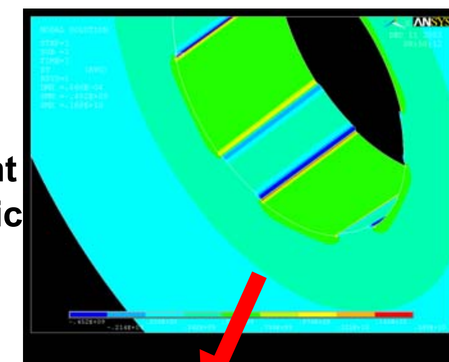
Probabilistic Modeling Summary

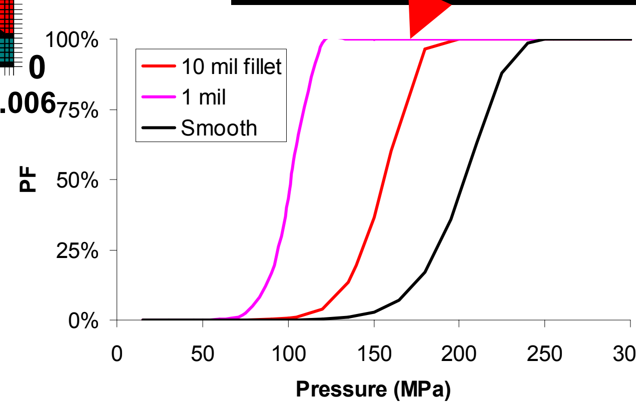
Validated probabilistic modeling capability for predicting the strength of ceramic lined gun tubes has been coupled with FEA models to assess:

- Transient thermal behavior
- Thermal shock on the bore surface
- Dynamic thermo-mechanical loading
- Rifling/engraving
- Projectile/barrel interactions

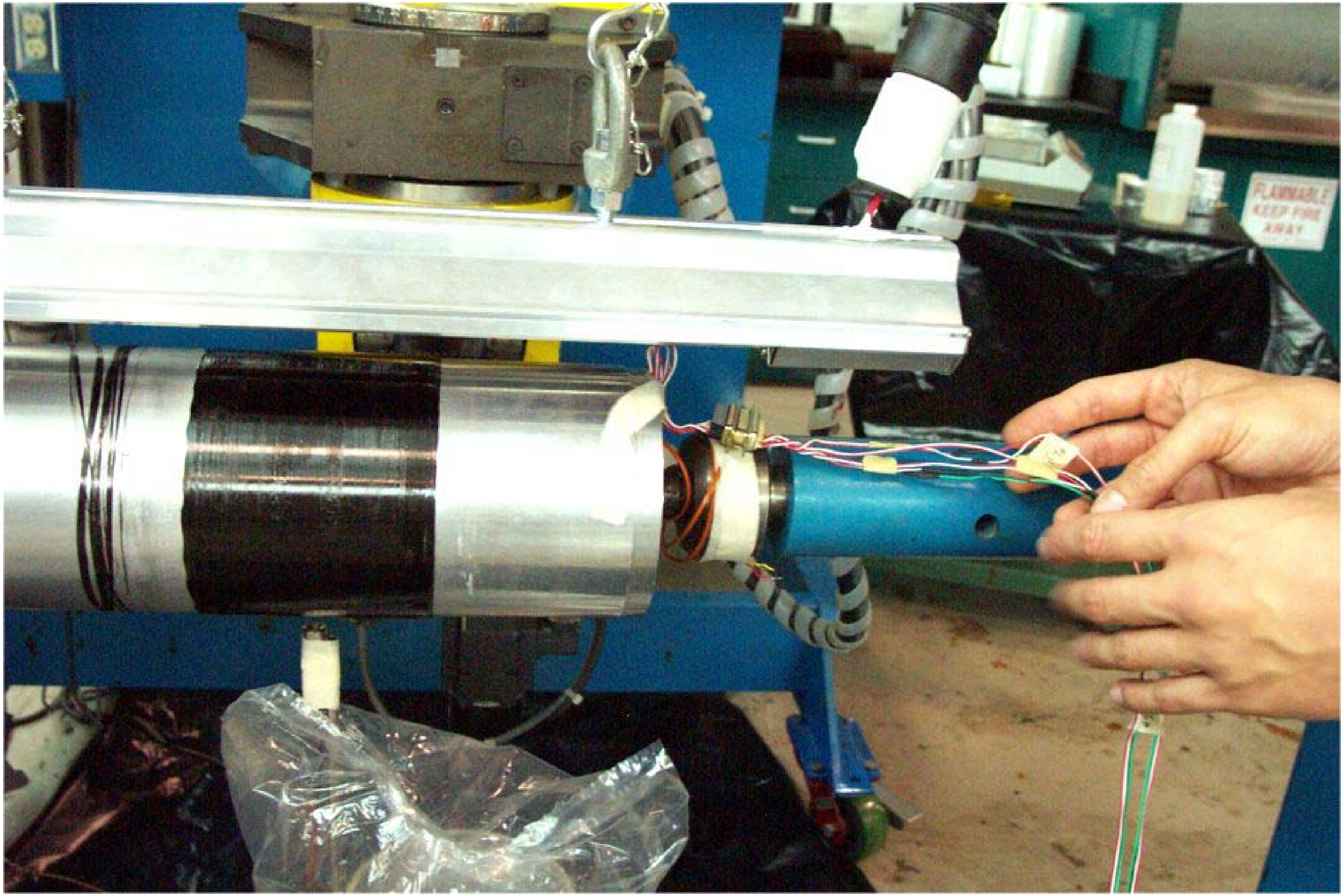




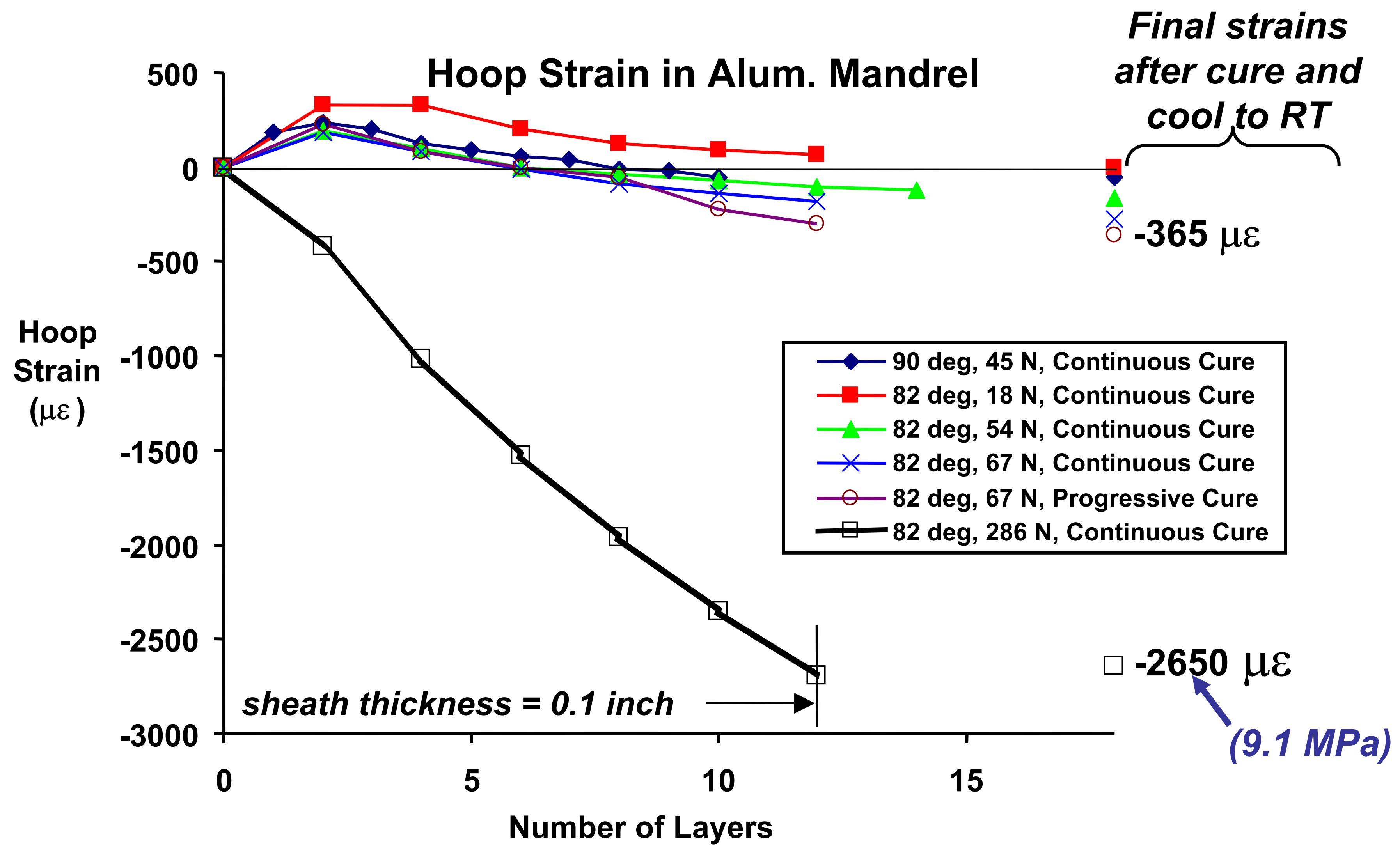




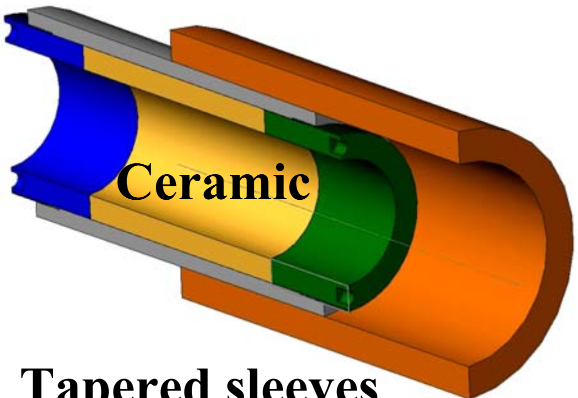
High-Tension Winding



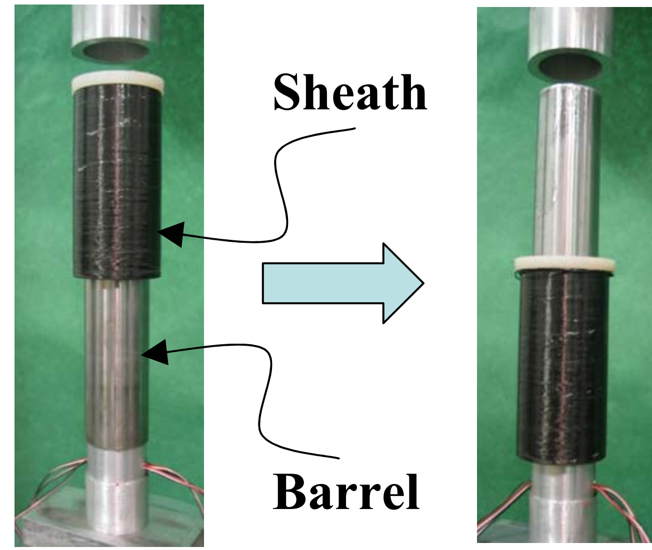
High-Tension Winding Results

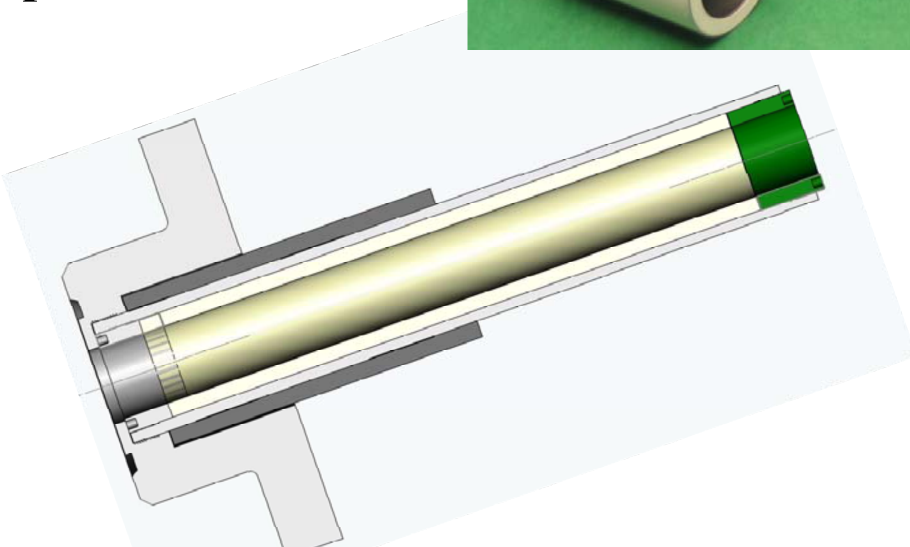


Multiaxial Sheathing

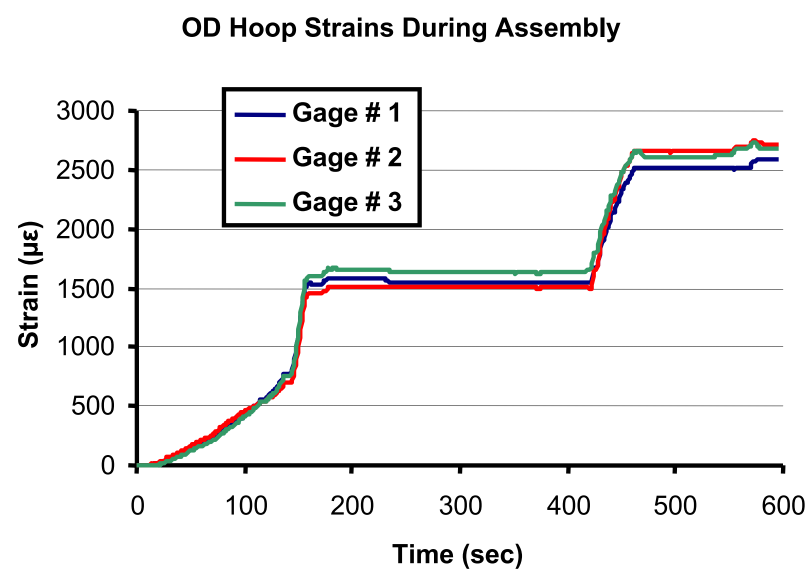


Tapered sleeves
for press-fit

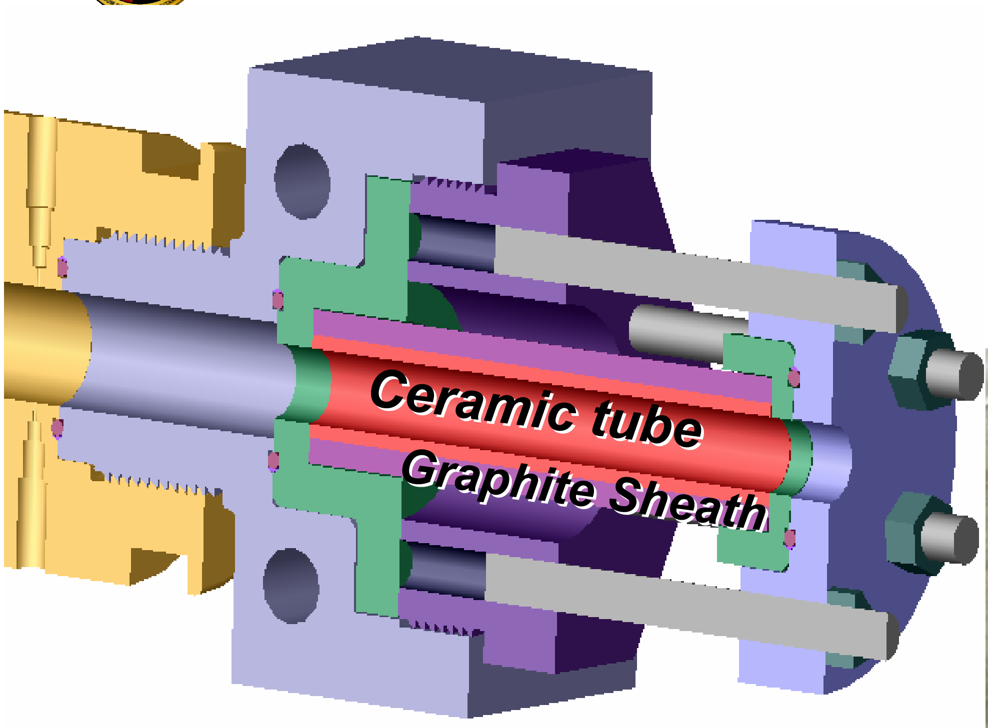




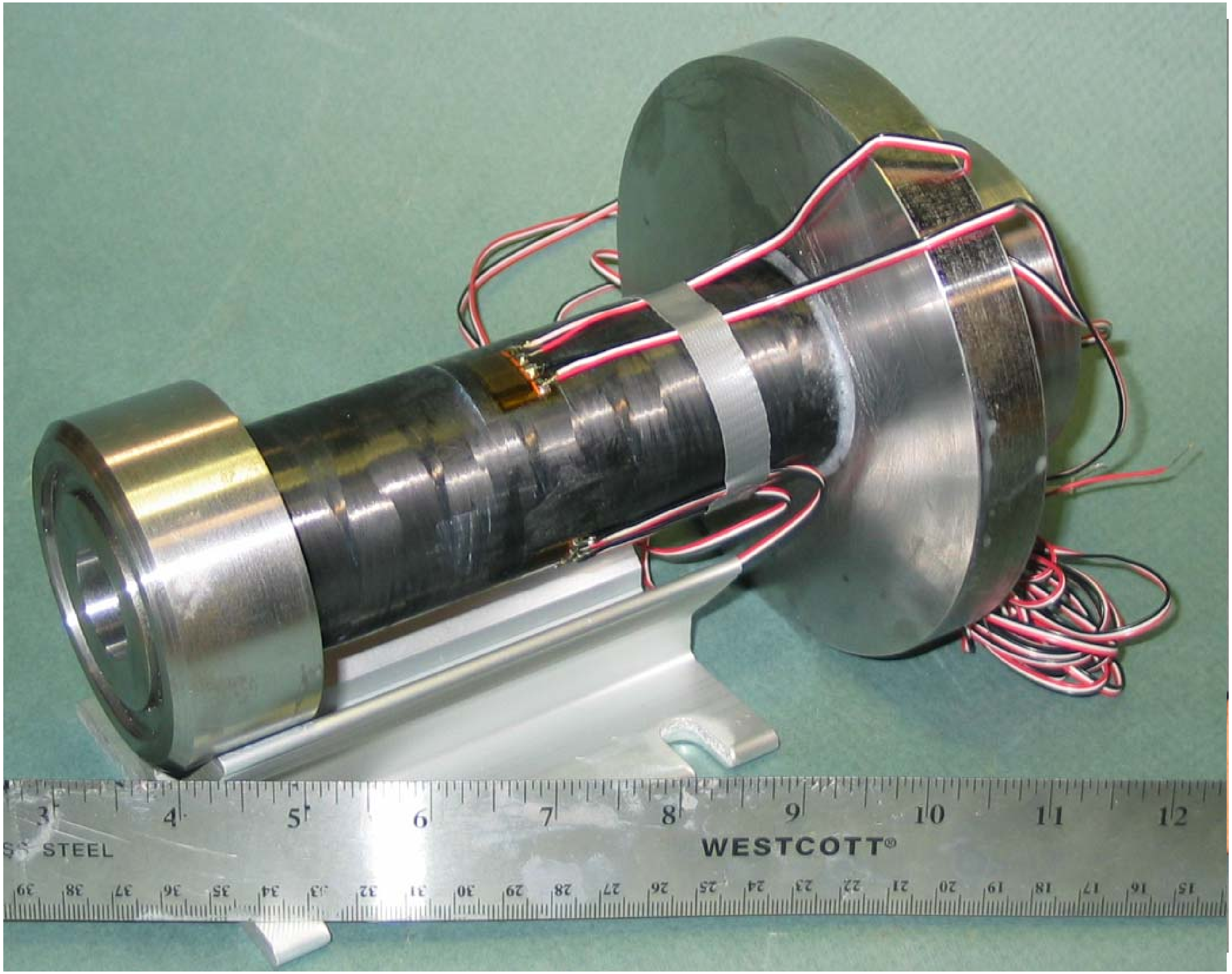
Demonstrated sheathing pressure
in excess of 200MPa



Ballistic Test Fixture



Ballistic Specimens



Firing History & Plans

- Four Si_3N_4 tubes with high-tension wind
  - Maximum pressure achieved ~45 ksi
  - Ceramic tubes crack but failure is not catastrophic
- Two SiAlON tubes with high-tension wind
  - Maximum pressure achieved ~25ksi
  - Issues with tube concentricity and the firing fixture have limited the achievable pressure
- Test of multi-axial confinement schemes planned by year end

Conclusions

- Identified commercially available ceramics for ceramic-lined gun barrel application
- Developed a probabilistic design approach to account for ceramic failure behavior
- Investigated robust sheathing schemes to provide the required level of compressive pre-stress
- Have conducted preliminary firing tests with 25-mm tubes achieving 45 ksi (in line with predicted limits of sheathing)

Future Challenges

- Imparting rifling without degrading the performance of the ceramic liner
- Manufacturing of longer, straighter, more concentric tubes held to tight tolerances