Development of Explosive Feedstock for Commercial-off-the-Shelf (COTS) 3D Printers

CAD/PAD
2022 Technical Exchange Workshop

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Lynntech Overview

2016 U.S. Small Business Administration (SBA) Tibbetts Award Winner

- **Technical Focus**: Develop and transition technologies to benefit soldiers, sailors, airmen, or marines.
- **Significant Technical History:**
  - Founded in College Station, Texas 1987
  - Thirty years of experience in developing and transitioning innovative technologies and systems based on applied electrochemistry.
- **Key Resources:**
  - ~100 employees (diverse disciplines)
  - ~70,000 sq ft facility
  - Collaborate with Universities, FFRDCs, Industry, DoD Prime Contractors
  - Facility clearance, QMS standards
  - Material, device, systems-level research and development
- **Proven track record of moving technology to market**
  - Several post-Phase II contracts for the Department of Defense.
  - Transition success (sales, spin-offs, licensing).

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Navy Operational Challenge

- Develop explosive feedstocks capable of being utilized in COTS 3D printer systems
- Navy Focus – Prototyping & Manufacturability
  - Improve testing of new energetic formulations
    - Speed, safety, cost
  - Improve scale up of energetic formulations
    - Mixing, pot life, temperature control
  - Identify performance metrics for printed energetics
    - Maintain/Improve metrics vs traditionally cast energetics
      - Strength, elasticity, burn rates, etc.
  - Demonstrate the ability to create unique forms and shapes
    - Customizable energetics

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Lynntech's Solution

- Develop multi-stage curable binders for energetic feedstock for use in COTS 3D printer systems
  - Modify known binders to enable photocuring when mixed with energetics
  - Demonstrate the ability to 3D print using known extrusion printing processes
- Develop chemistries for additive modifications
  - Modify known additives to reduce viscosity and improve extrusion properties

Immediate Benefits:

- Enables the extrusion (3D Printing) of current/existing formulations
- Fast partial curing allows for printing of 3D objects
- Eliminates the need for long-duration thermal curing
- Volumetric scaling problem (of curing) greatly reduced through the combination of *in situ*/post-process photo-cure methods

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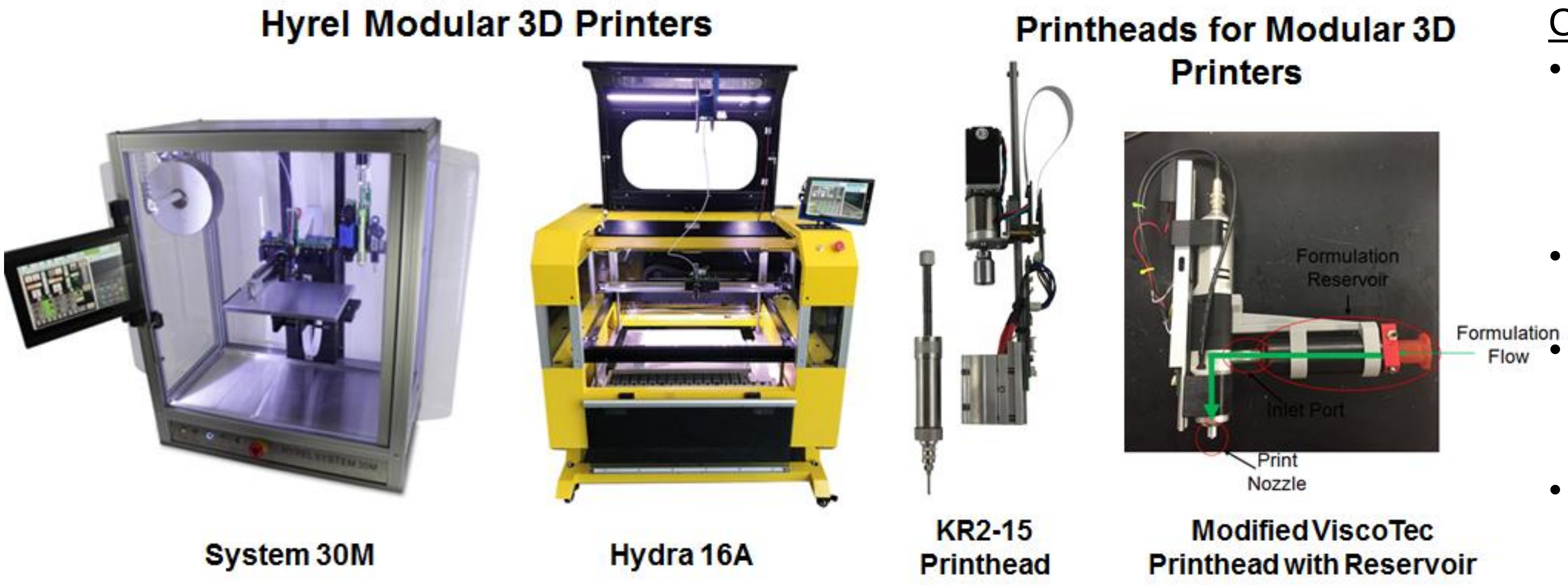
COTS 3D Printers/Printheads Utilized by Lynntech



Current Capabilities:

- Maximum Print Speed Achieved with AP/ATPB/HTPB Mixtures: 10mm/s
- AP Solids Loading: 80-90% (wt%)
- Extrusion Nozzle Inner Diameter: 14-20 Gauge (0.6 – 1.6mm)
- Formulation Print Temperatures: 25-80˚C

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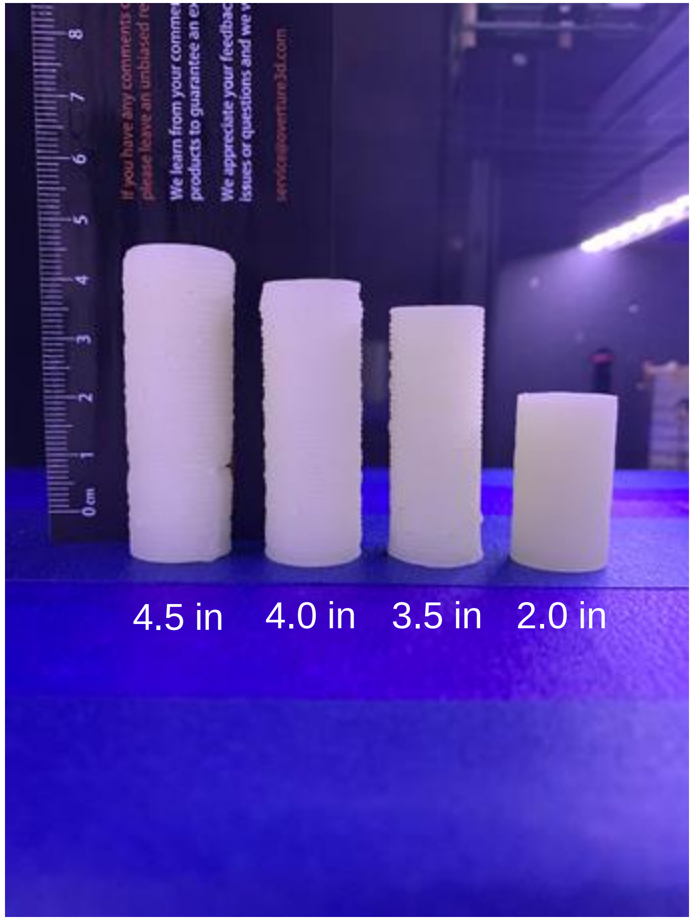
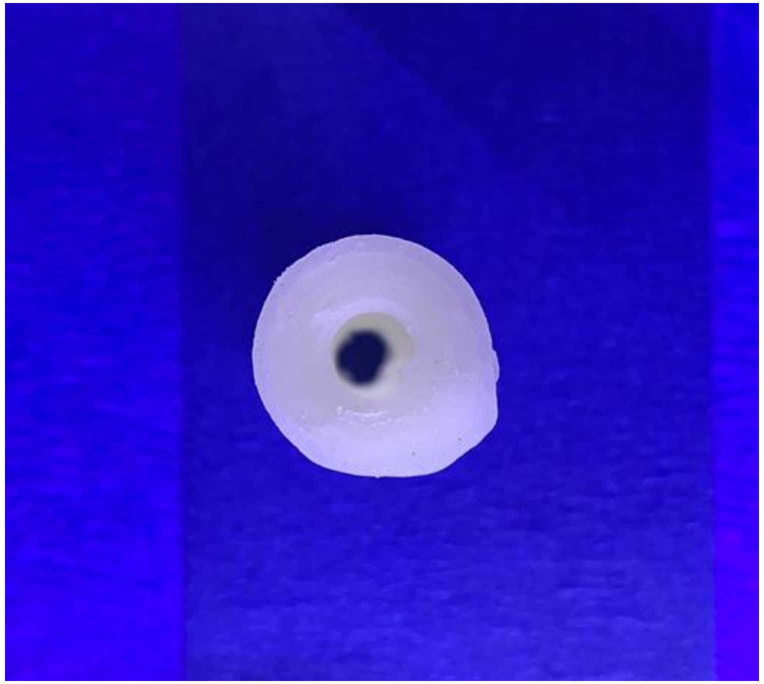
Baseline Prints Using COTS Equipment



Prints utilizing UV-Curable Binder Formulations

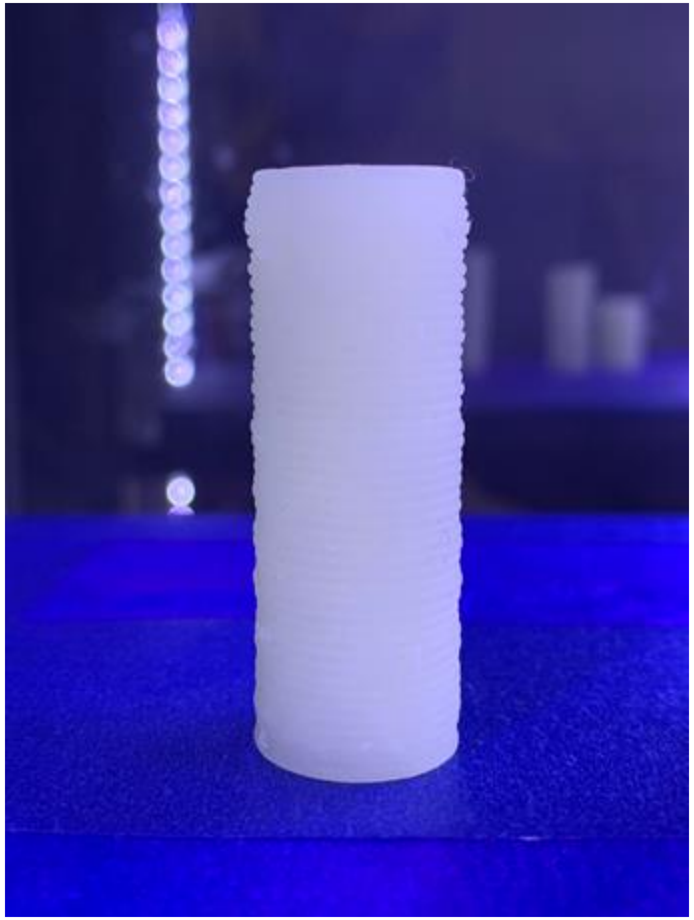


- 20% Binder
- 80% Ammonium Perchlorate
  - 40% 45µm
  - 40% 90µm
- UV Curable Formulation

science | evolved

Prints Using Different Nozzle Diameters

14 Gauge Nozzle (1.6µm diameter)



20 Gauge Nozzle (0.6µm diameter)

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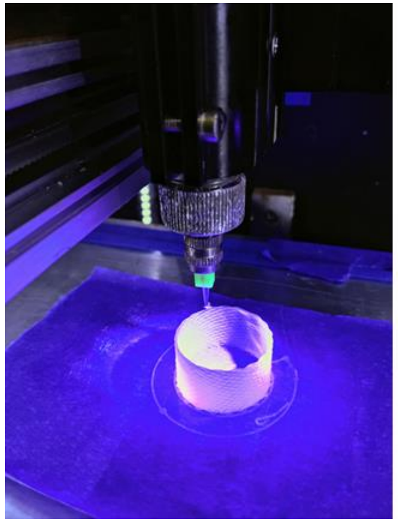
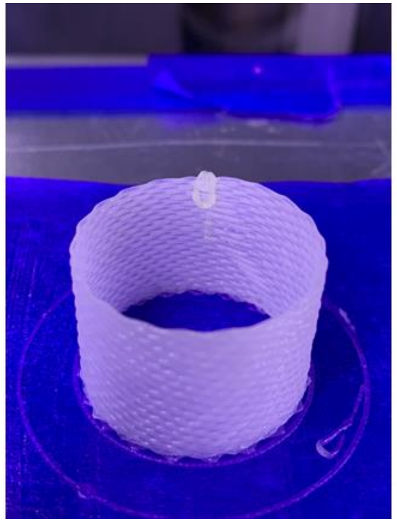
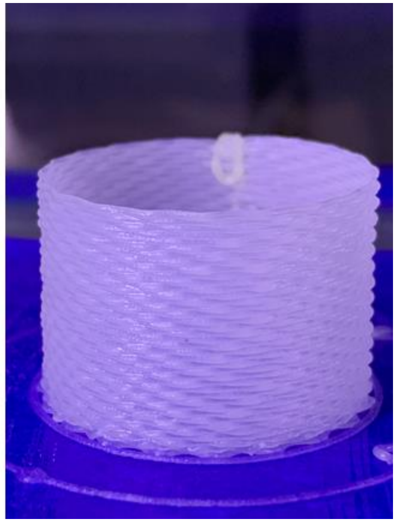
Print Capabilities

Complex Designs

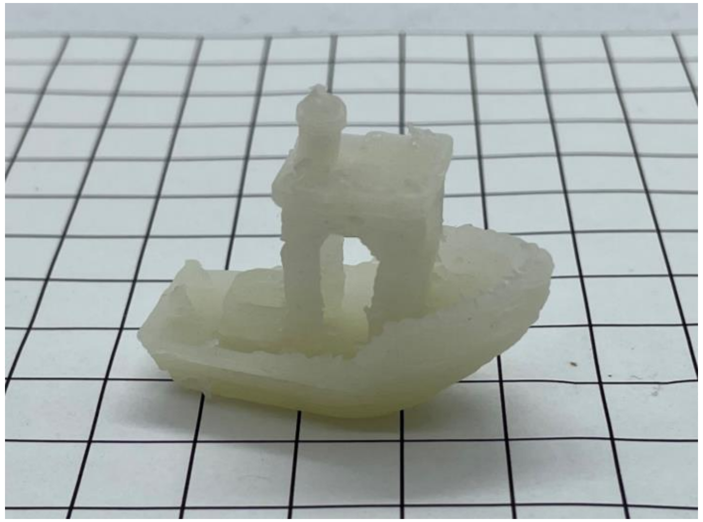
Thin-Walled Prints







Prints requiring retraction



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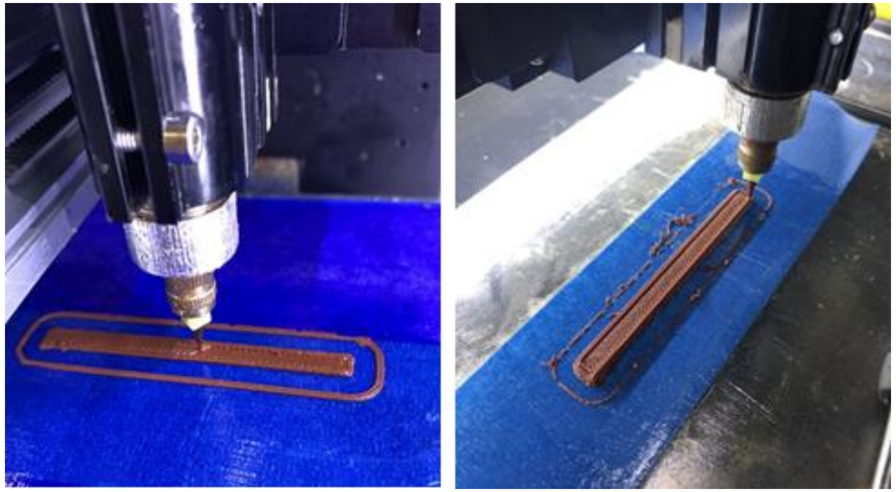
Main Issues with 3D Printing APCP Formulations



<u>Problems to be overcome for 3D printing</u>

- Additives make formulation un-extrudable
  - High viscosity
  - High non-Newtonian properties (pressure thickening)
  - Thinning solvents hurt curing properties
- Highly viscous nature of formulations prevent 3D printing with the required high resolution and reproducibility necessary for performance and utilization
  - Necessary shapes
  - Necessary burn metrics
  - Leads to failures caused by voids and air gaps
    - Causes fast flame propagation

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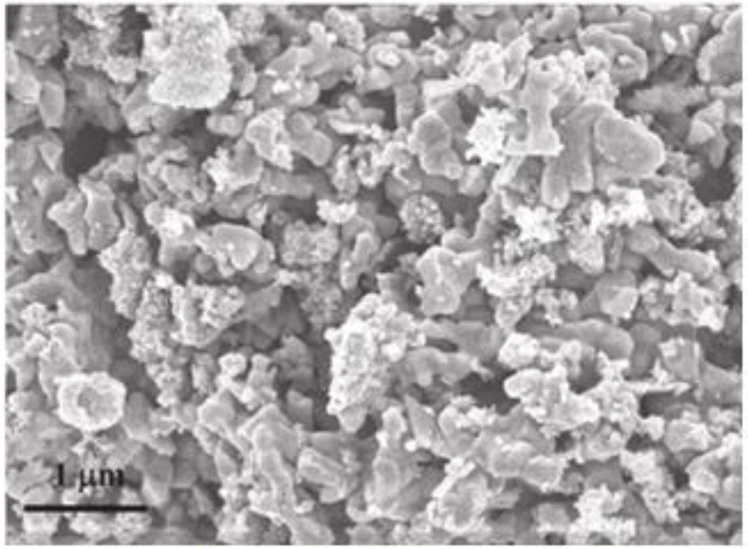
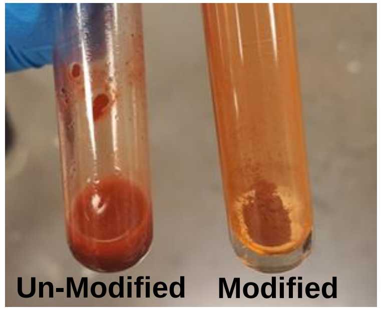
Modification of Additives for use (*example*)

SEM of Iron Oxide



High Surface Area, Irregular shapes

In Water



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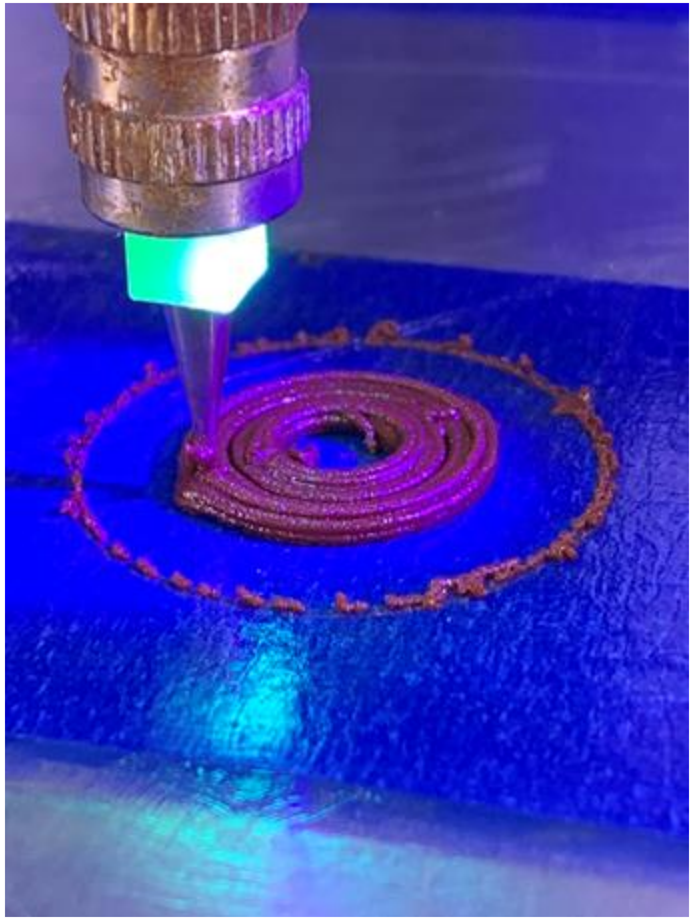
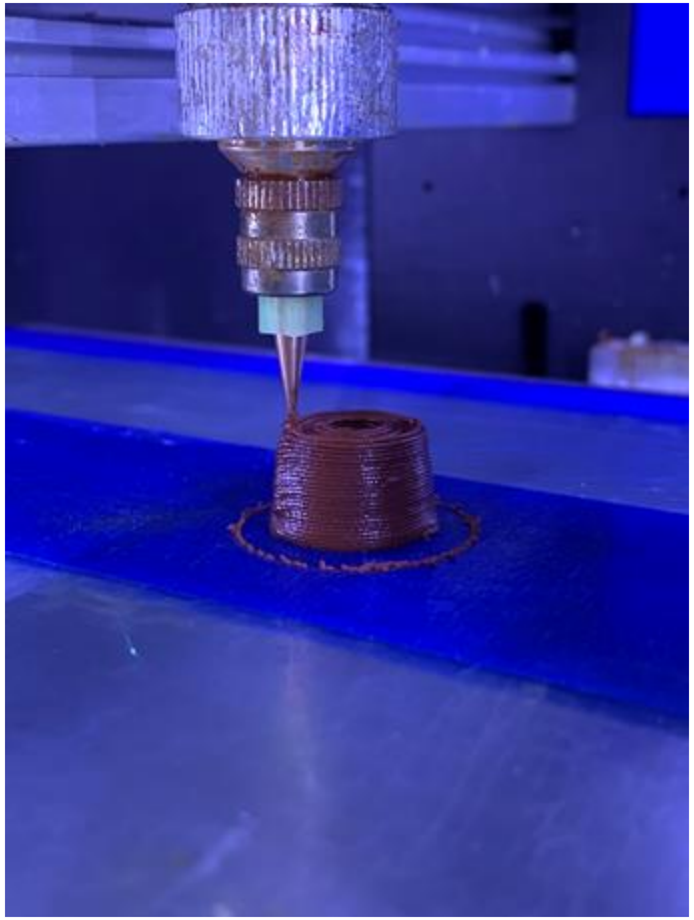
Printing using Modified Formulation





Burn Testing

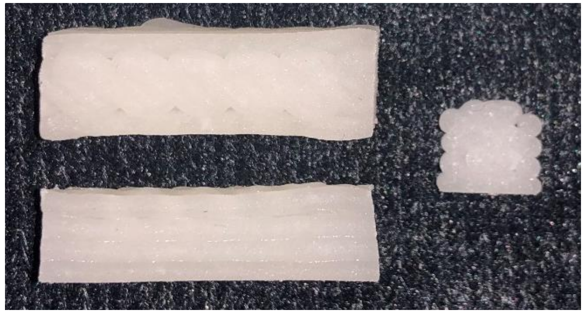
Burn Rate Tests of Printed Strands

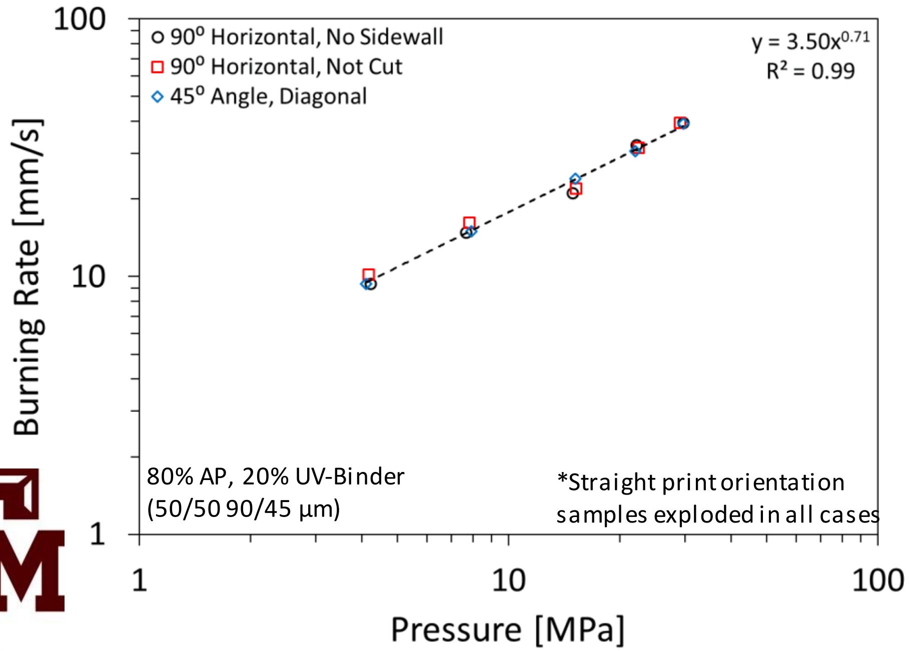
Straight

90º Horizontal, No Sidewall

90º Horizontal, No Cut

45º Angle, Diagonal





Voids/Imperfections in the Printed Strand

__Key Findings:__

– Burning rate is not directly dependent on print orientation
– High-quality printing is required for consistent ballistics

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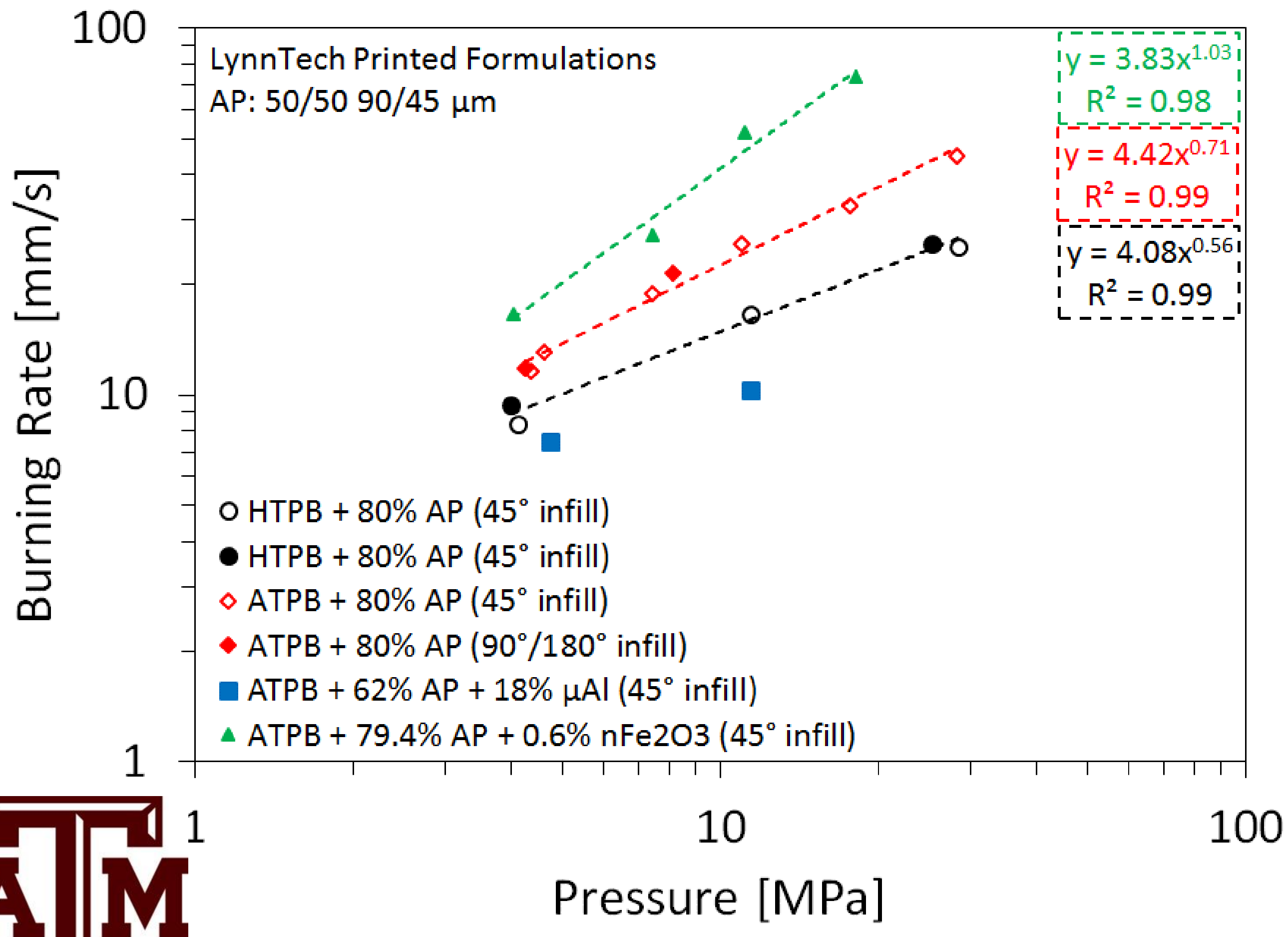
Burn Rate Tests with Additives

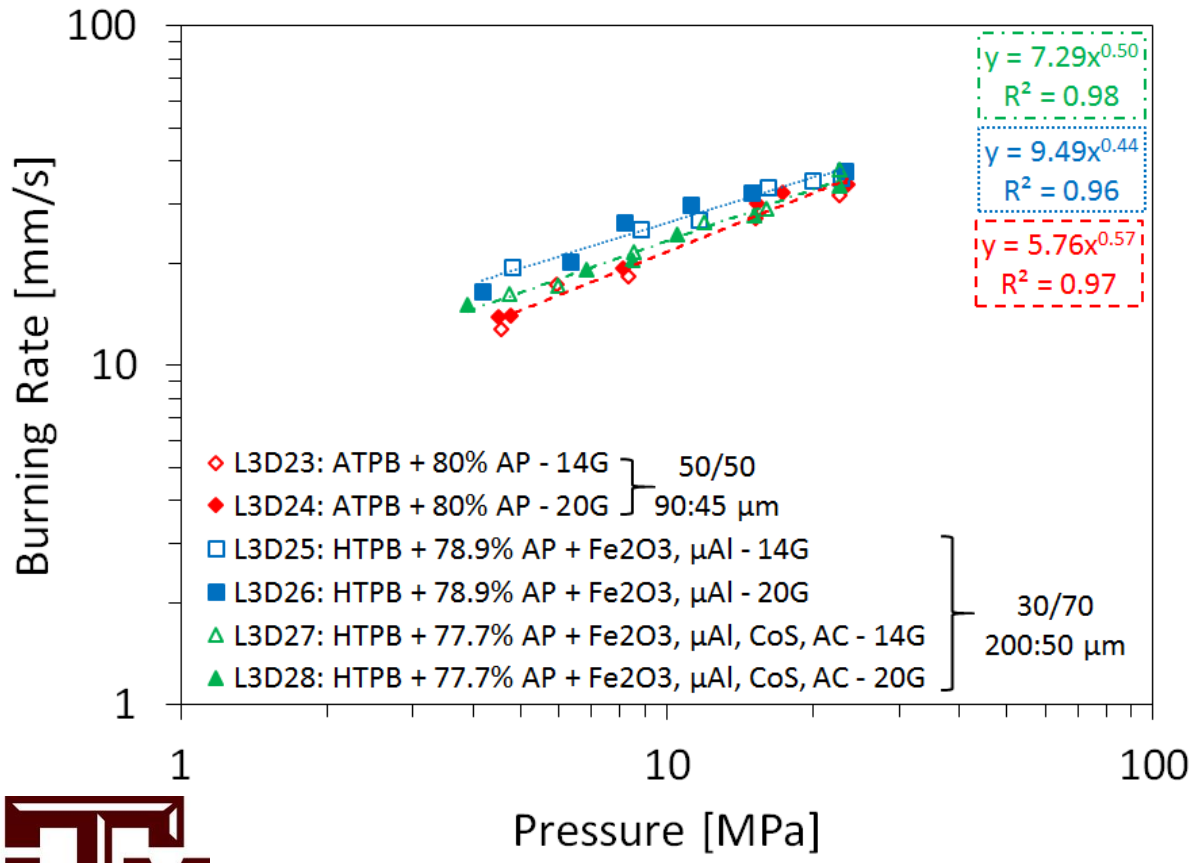


Key Findings:

- High-quality printing required for consistent ballistics
- Burning rate is not directly dependent on print orientation
- Expected additive trends captured

Batch	Formulation	Orientation	Density (g/cm^3) AVG	St Dev
L3D16	20% HTPB + 80% AP (50/50 90:45)	45° infill	1.37	0.080
L3D17	20% HTPB + 80% AP (50/50 90:45)	45° infill	1.28	0.055
L3D18	20% ATPB + 80% AP (50/50 90:45)	45° infill	1.41	0.050
L3D19	20% ATPB + 80% AP (50/50 90:45)	90°/180° infill	1.39	0.023
L3D20	20% ATPB + 80% AP (50/50 90:45)	concentric infill	1.39	0.040
L3D21	20% ATPB + 62% AP (50/50 90:45) + 18% µAl	45° infill	1.10	0.053
L3D22	20% ATPB + 79.4% AP (50/50 90:45) + 0.6% *n* Fe_2O_3	45° infill	1.19	0.056

APCP Propellant Burn Rate Data



Batch	Nozzle Gauge	Density (g/cm^3)	
		Lynntech	TAMU
L3D23	14	1.38	1.38 ± 0.06
L3D24	20	1.38	1.42 ± 0.06
L3D25	14	1.35	1.38 ± 0.13
L3D26	20	1.32	1.51 ± 0.03
L3D27	14	1.33	1.40 ± 0.10
L3D28	20	1.37	1.47 ± 0.10

Key Findings:

– Burning rate is not directly dependent on printing gauge

– Expected additive trends captured

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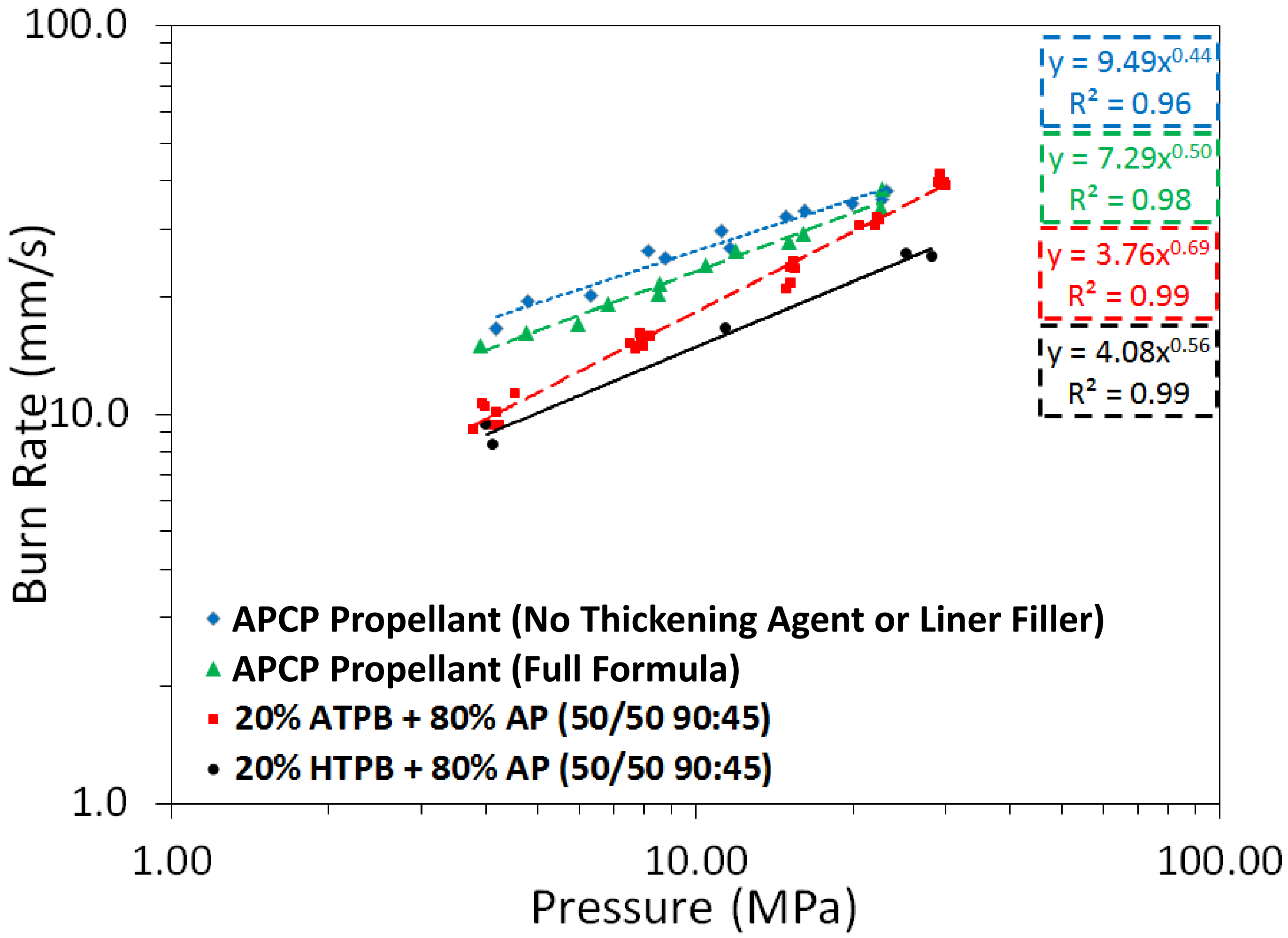
Burn Rate Comparisons



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