Additive Manufacturing of High Solids Loading Hybrid Rocket Fuel Grains

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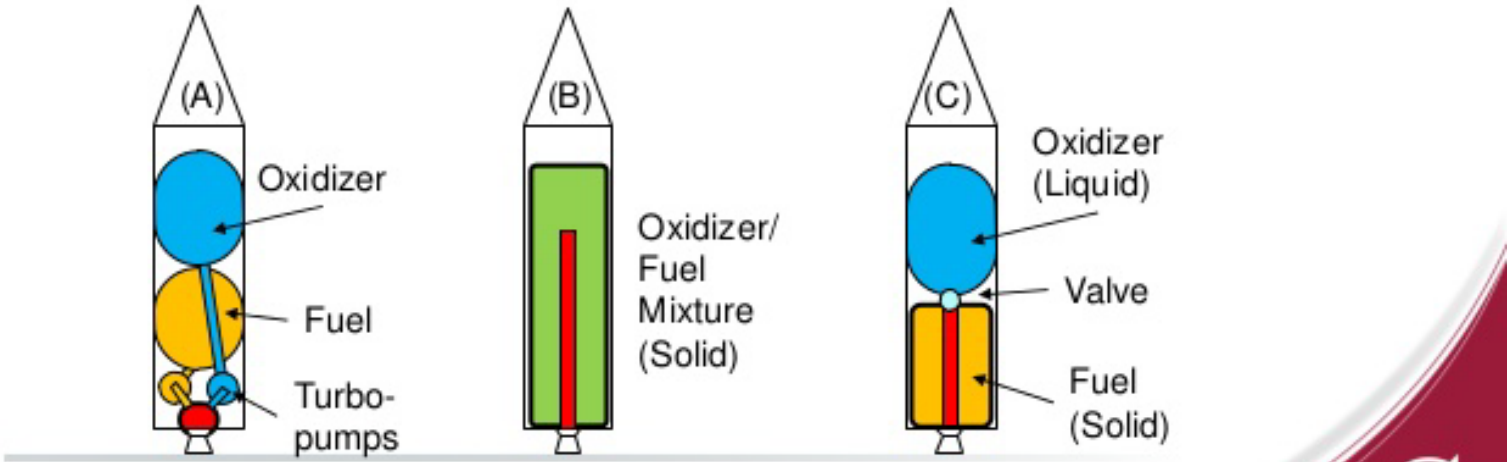
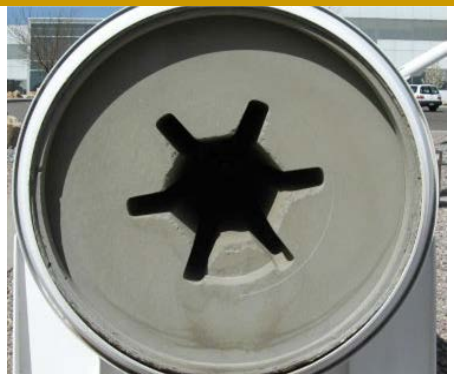
Background

- Liquid Rocket
  - Safe - fuel and oxidizer separate
  - Complicated and expensive
- Solid Rocket
  - Dangerous – fuel and oxidizer mixed
  - Simple and cheap
- Hybrid Rocket
  - Safe – fuel and oxidizer separate
  - Relatively simple and affordable



Background

- Slow regression rate hinders performance.
- Energetic additives
- Complicated port geometries create more burning surface area.
  - Hard to cast



Gear port example [1]

Benefits of 3D Printing Hybrid Fuel Grains

- Easier to make complicated port geometries
- Can make spiraling port geometries
  - Can increased regression rate 230% [2]
- Hard to 3D print with additives

Spiralling port fuel grain [3]

[1] Goebel, Greg. 2016. "Chemical Rocket Systems." *Air Vectors*. January 1. http://vc.airvectors.net/tarokt_1.html#m4.

[2] D. Armold, J. Eric Boyer, K. Kuo, J. K. Fuller, J. Desain, and T. J. Curtiss, "Test of Hybrid Rocket Fuel Grains with Swirl Patterns Fabricated Using Rapid Prototyping Technology," in *49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference*, 2013.A

[3] https://en.wikipedia.org/wiki/Hybrid-propellant_rocket

Fused Deoposition Modeling

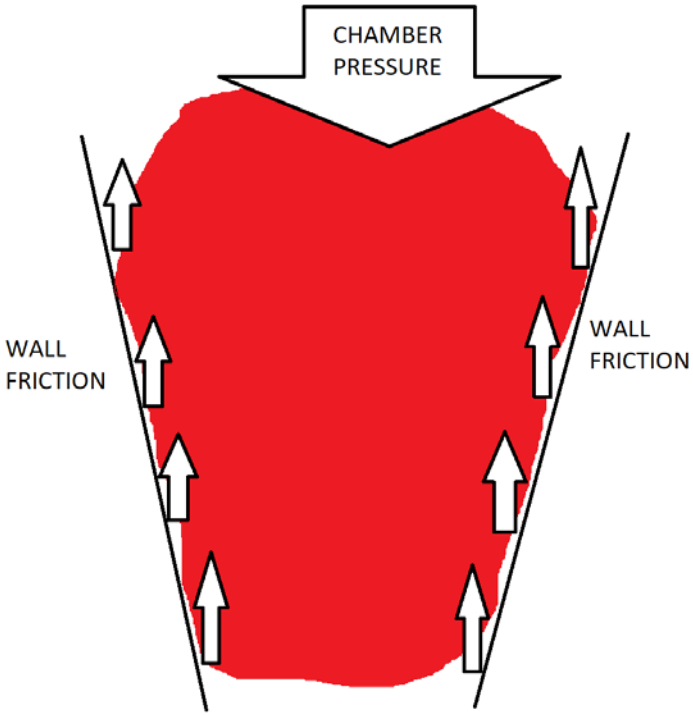
- Extrudes one layer at a time
- Material fuses together
- Common printer
  - Heated plastic filament

FDM Printer [1]

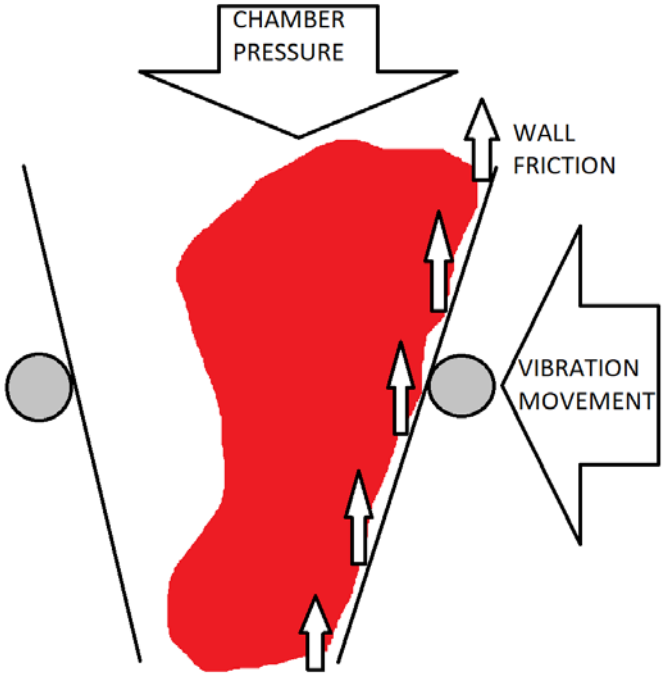
[1] https://www.additive3d.com/extrusion-deposition-fused-deposition-modeling-fdm/

High Viscosity Printer

- Wall friction controls flow rate
- Ultrasonic Vibration Transducer – reduces wall friction and thins fluid



Typical FDM printer tip



Proprietary printer with transducer

Methods

Prepping samples:

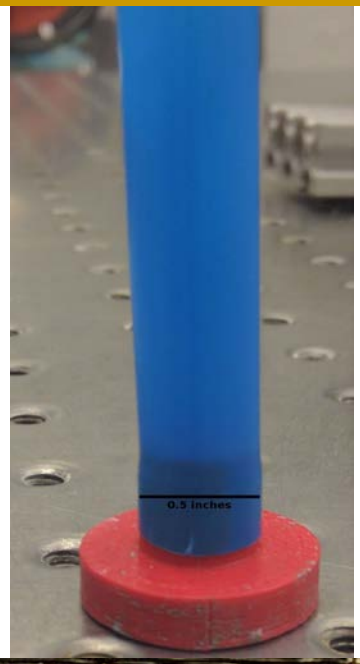
1. Weigh materials
2. Hand mix
3. Resonance mixing
4. Degas
5. Cast or print
6. Cure

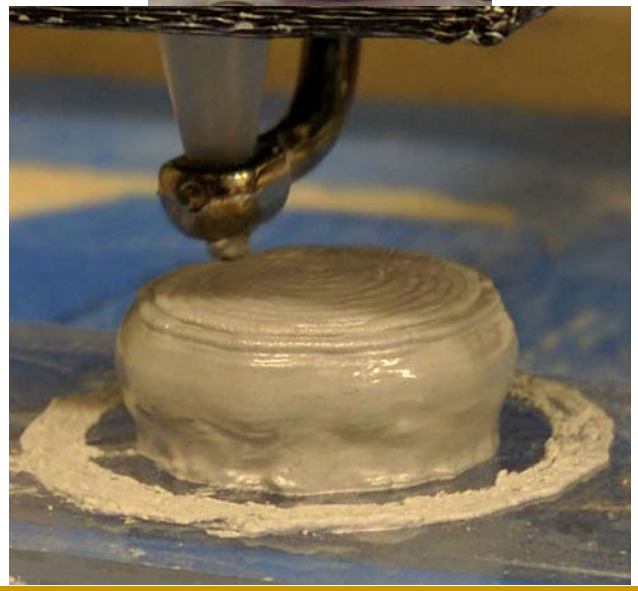
Cast Samples:

- Half-inch diameter straws with 3D printed ABS plug used as molds

Printed Samples:

- Loaded into syringe immediately after degasing





Results

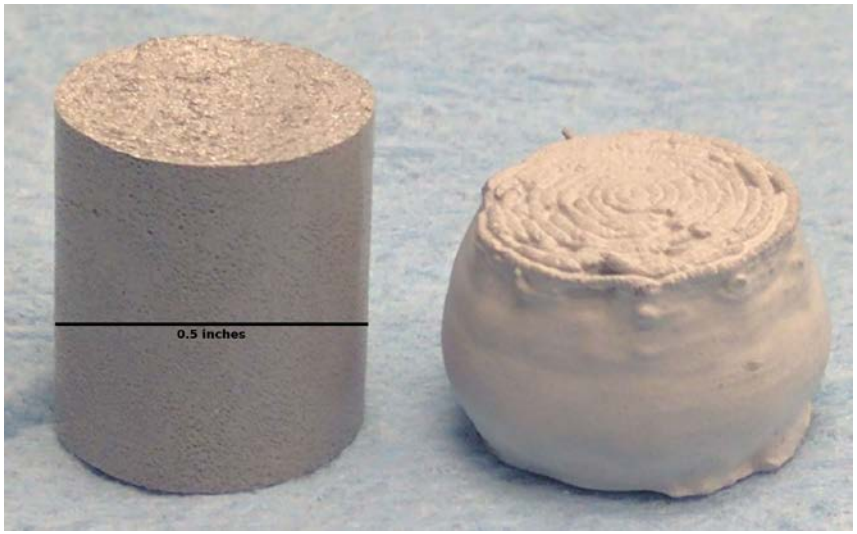
85% AL-HTPB

- Was able to be printed
- Creep was significant
  - Caused bulging and sagging
  - More complete infill and fully dense interior
- Can’t print tall samples with the sagging

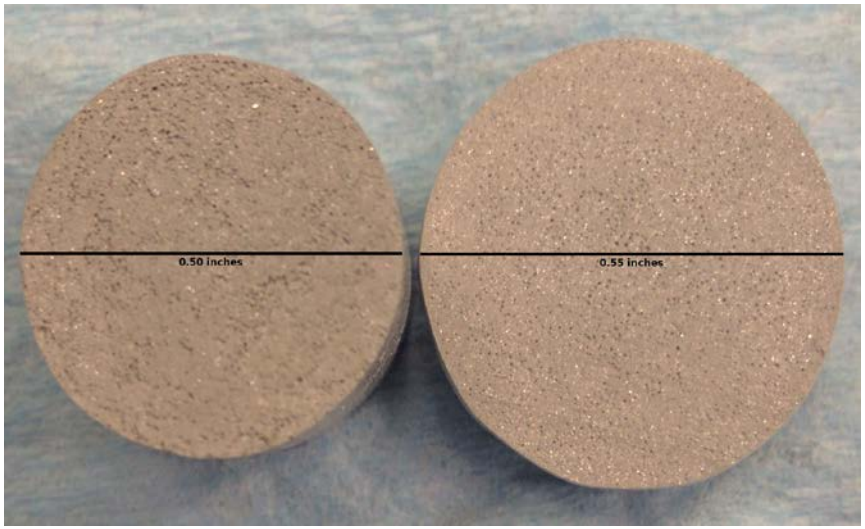
80% AL-Sylgard

- Heat caused it to set and clog during early tests
- Lower duty cycle and more effective cooling needed

Microbubbles were prevalent in all samples.



85% Al-HTPB surface comparison

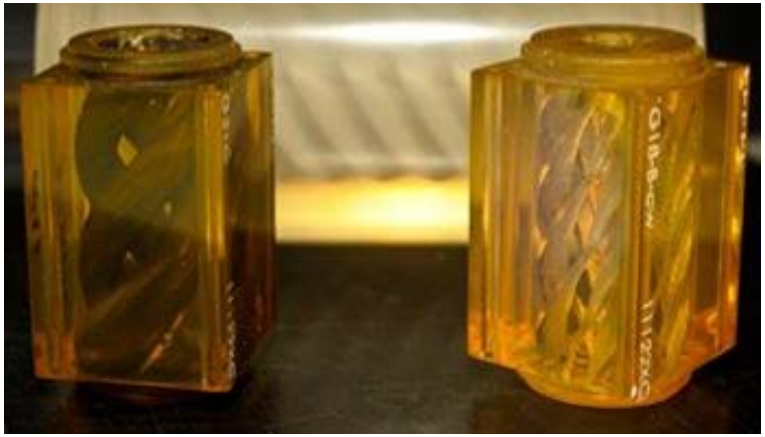


85% Al-HTPB cross section comparison
left = cast, right = printed

Future Work

- Investigate how to avoid creep:
  - Different binders
  - Different HTPB formulations
- Improve extruder head cooling system
- Different energetic additives and fuel types.
- Compare burning rates between cast and printed fuels
  - Motor tests
- Effect of spiraling port geometry

Liquid cooled 3D printer extruder [1]



Burned and unburned spiral port fuel grain [2]

[1] https://dyzedesign.com/shop/hotends/dyzend-x-hotend-1-75mm-liquid-cooled/
[2] http://www.aerospace.org/news/highlights/aerospace-prints-rocket-motors-in-3-d/

Opposed Flow Burner

- Set up and tested the Opposed Flow Burner
- Successfully burned HTPB & 10% Al-HTPB
  - Comparable burn to previous work
- Ash buildup on Sylgard prevented burning
  - Higher flow rate may help

O.F.B. - Issues

- 85% Al-HTPB didn't burn
  - Melted, aggregated, then ejected
- Samples were too wide for stand
  - Stayed put instead of moving up
- O.F.B. may not accurately simulate hybrid motor with energetic additives

10% Al-HTPB sample after burn test

Questions?