Abstract

Designing Additively Manufactured Energetic Materials Based on Property/Process Relationships

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Abstract:
This presentation gives an overview of approaches to control the property-processing relationship for powdered energetic materials processed using extrusion-based additive manufacturing methods. The materials of interest include both slow-burning propellants and explosives, as well as different kinds of binders and coating materials to manage and control the reactive materials. Given the requirements for shaped and tailored energetic materials, traditional molding and casting processes are automatically excluded from consideration. Due to its ability to produce good-quality materials with very high (>90%) powder and fiber loadings and thermoplastic binders, the powder material extrusion (PME) additive process can be used as the basic manufacturing process. In addition, this process is simple to operate technically, is relatively-low cost and operating temperature, is very safe for operators, does not need any kind of shielding gas or vacuum to operate, and can be used in an expeditionary environment with a restricted energy supply. While the process typically operates by melting binder in the powder feedstock (typical extrusion temperatures are 180-260°C), it can also work at ambient (20-30°C) temperatures if an appropriate binder is used. This gives more control options for the different kinds of reactive materials that could be used, as well as removing operator risk.

Keywords: Energetic materials; additive manufacturing; low-energy manufacturing; powder-based manufacturing

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Design for Additively Manufactured Energetic Materials Based on Property/Process Relationships

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Introduction

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- Powder-based additive manufacturing of energetic materials is an emerging topic of research.
- Energetic materials are typically used as propellent and explosive charges for a variety of applications.
- Given the requirements for shaped and tailored energetic materials, traditional molding and casting processes are automatically excluded from consideration.
- Powder material extrusion (PME) is an additive manufacturing processes which combines fused filament fabrication (FFF) and powder injection molding (PIM).
- The feedstock is powder (60-90%) held together using a thermoplastic binder (10-40%).
- For structural parts, the green parts typically need to be debinded and sintered to be useful, but green parts can be used directly when the intended use is energetic forms and charges.

Energetic Materials

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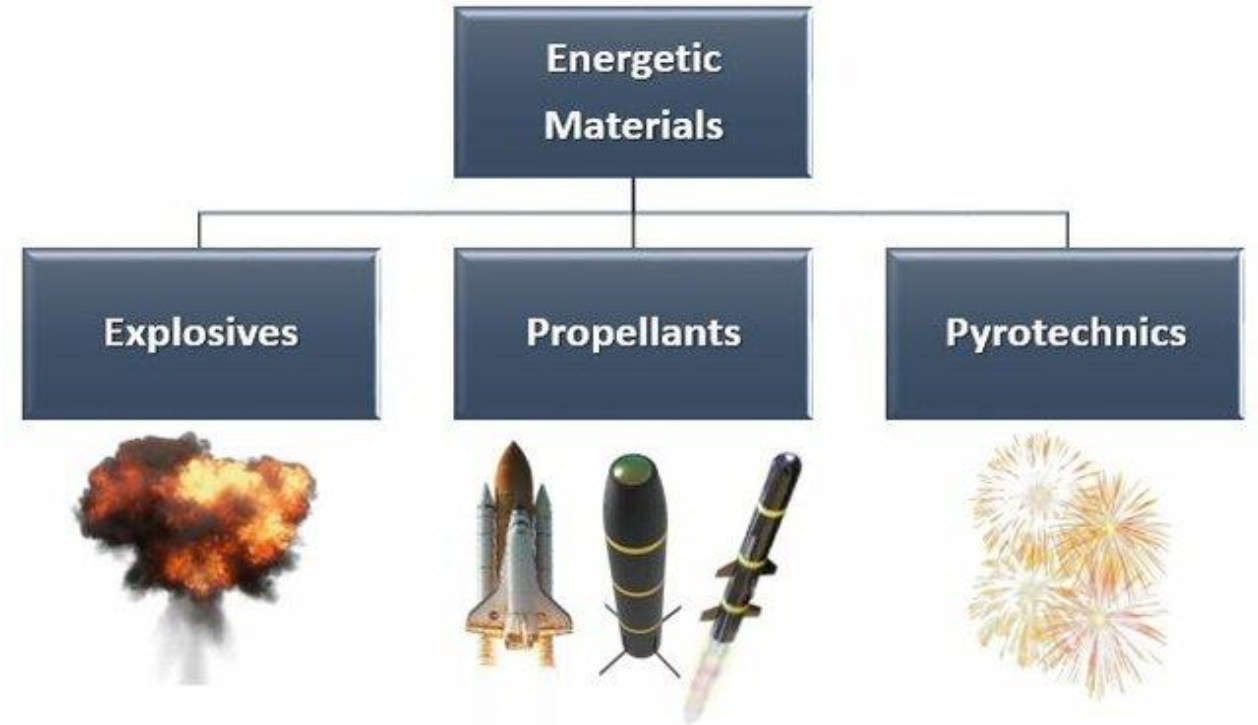

Reference: Gok & Cihan (2020). Energetic materials and metal borides for solid propellent rocket engines. *The International Journal of Materials and Engineering Technology, 3*: 109-119.

Reference: Osmont & Lefrancois (2022). Overview of energetic materials. *Theoretical and Computational Chemistry, 22*: 3-27.

Q: Why is understanding these materials important?

Grain Manufacture

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Casting

- The “grain”:-shaped mass of solid propellant inside the rocket motor.
- Removal of the solid mandrel.

  Difficult and dangerous to remove (electrostatic discharges, grain damages)

Machining

- Difficult, dangerous, limited, and costly.

Limitations

- Less geometric freedom internally
- Unable to make internal holes, columns, etc

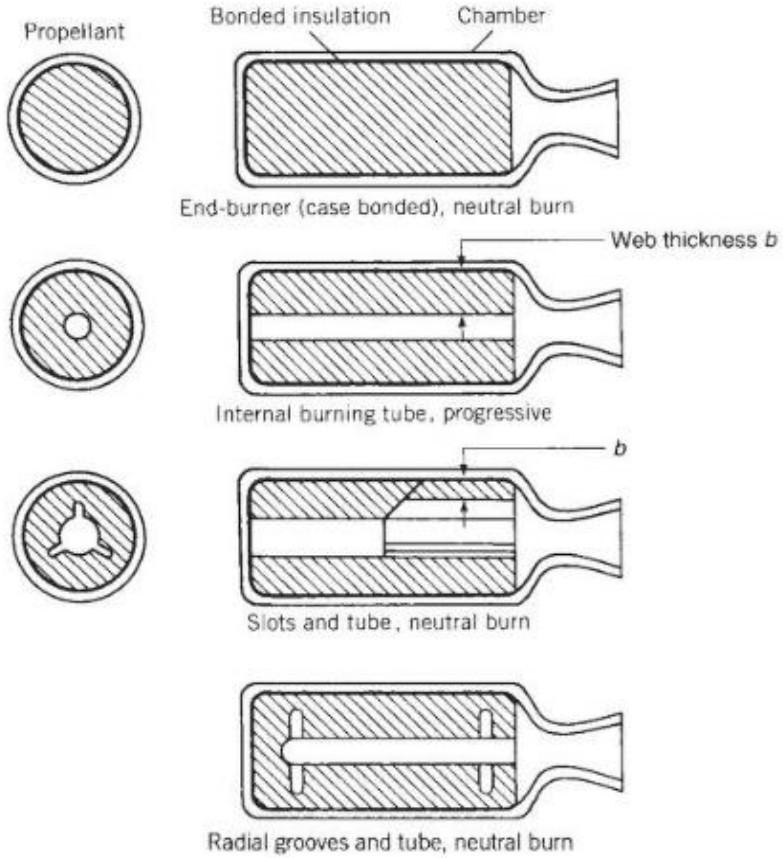
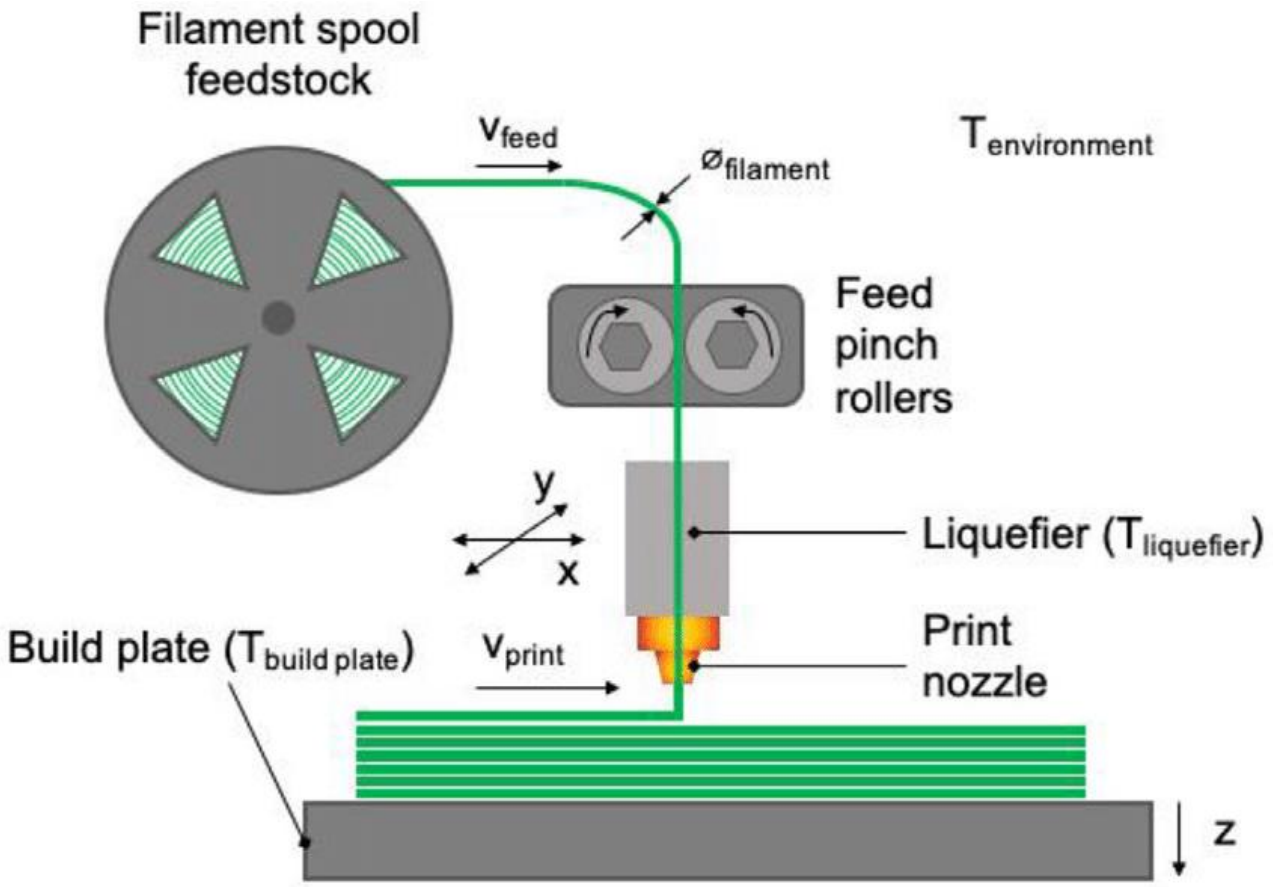


Fig. 12-6., Sutton, G., Rocket Propulsion Elements, 9th ed.

Q:Why continue with costly and dangerous methods when new technologies offer safer alternatives?

Green Part Shaping



Gains:

- Low energy consumption (4 kW)
- Low binder melting temperature (typical extrusion temperatures are 180-260°C), it can also work at ambient (20-30°C) temperatures if an appropriate binder is used.
- Can be used in expeditionary environment with a restrict energy supply.
- Less human interaction
- High fidelity (200 micron thick -400 micron wide)
- Customized thrust profile

Reference: Vaes, Dries & Van Puyvelde, Peter. (2021). Semi-crystalline feedstock for filament-based 3D printing of polymers. Progress in Polymer Science. 118. 101411. 10.1016/j.progpolymsci.2021.101411.

Q: What makes FFF a better manufacturing alternative for making solid propellant?

Design Objectives

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- For powder-based energetic materials, the most important consideration is the accurate shaping of the parts.
- Since PME can use many different thermoplastics as binders and most energetic material shapes will not need to be debinded, density and stiffness are easy to control.
- Excellent geometries are possible, including those with overhangs, bridges, and hollow areas.
- Lattice structures and those designed using topology optimization are feasible to manufacture using this method.
- Water-soluble and biodegradable binders will help ensure that lost material can become inert when not used and prevent accidental explosions or environmental contamination.

Design Objectives

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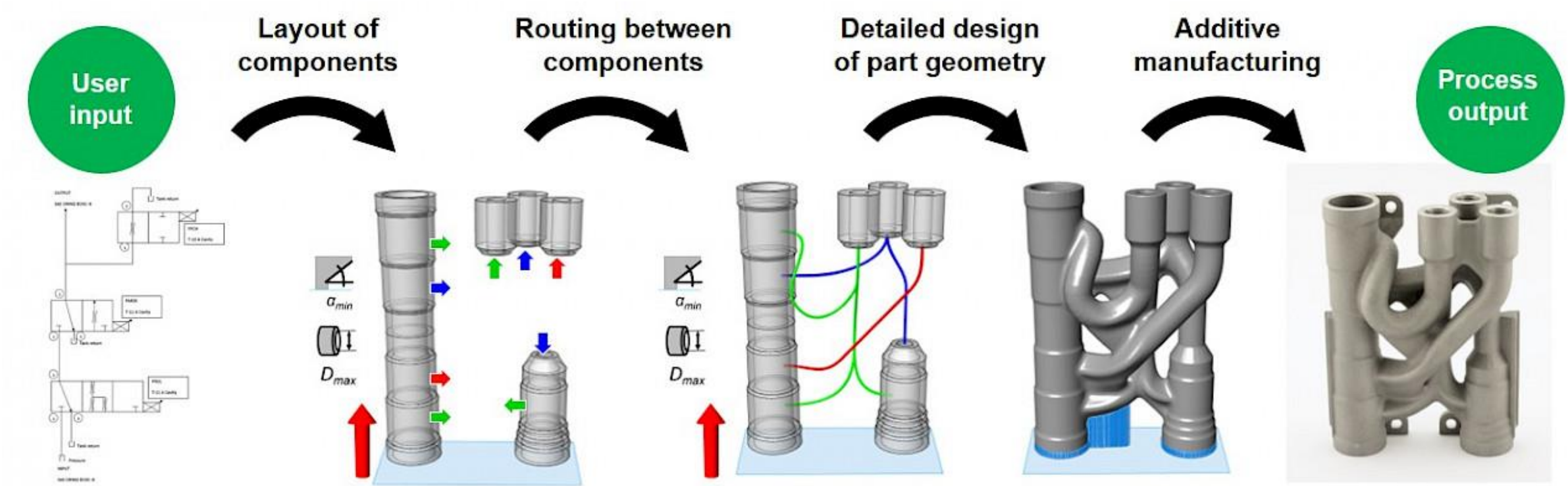

Reference: https://www.inspire.ch/en/research-for-the-industry/additive-manufacturing-3d-print-design-for-am/design-for-am/

Process-Property Relationships

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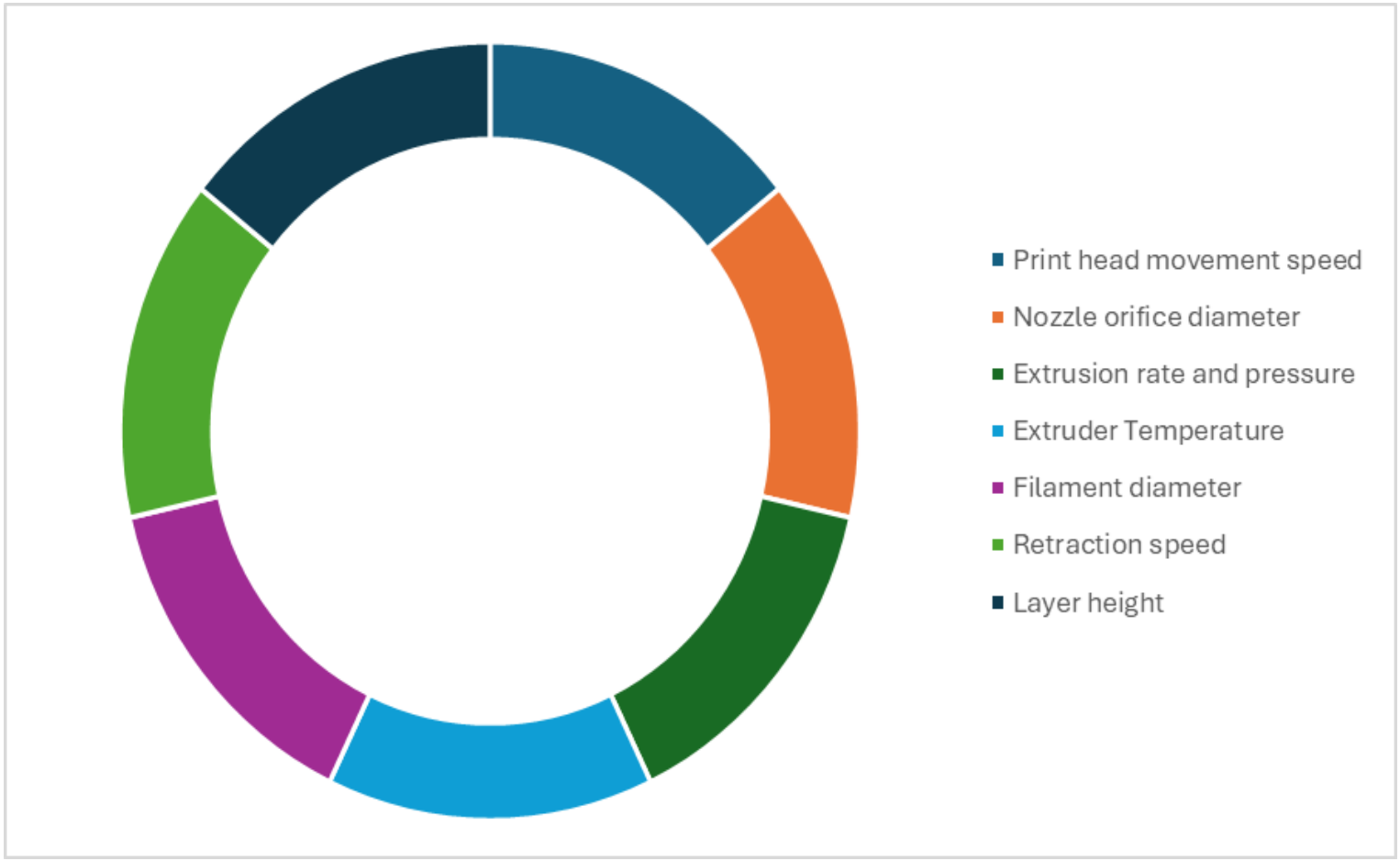

Getting a nice cohesive sample with minimal defects and internal pores for optimal performance of our part is a big challenge. Serious work is required for getting the printing parameters sweet spot!

Closing Remarks

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- Safe and low-cost additive manufacturing of energetic materials is an important emerging area of research .
- PME is a possible solution for this problem, due to the process mechanics and lack of significant energy input into the raw materials during processing and the available design freedom.
- Mechanical properties of green parts (most common case for energetic materials) can be controlled by choice and composition of binder.
- Major properties of the energetic material from a performance perspective (explosive, propellent, etc.) can be studied, predicted, and controlled by taking advantage of the clear coupling between process and properties for PME.

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Thank you for listening!

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