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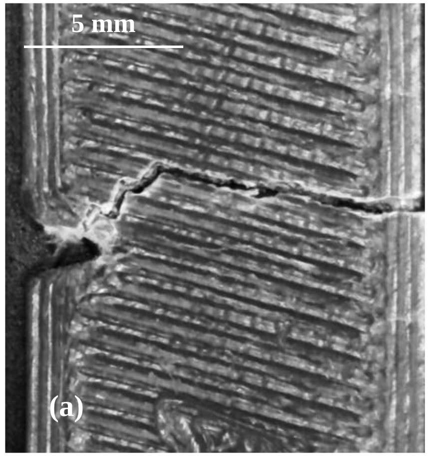
Design Opportunities Using High-Density Extrusion-Based Additive Manufacturing for Impact Problems

Albert E. Patterson, PhD
Assistant Professor – Manufacturing and Mechanical Engineering Technology
Department of Engineering Technology and Industrial Distribution
J. Mike Walker ‘66 Department of Mechanical Engineering (Affiliate Faculty)
Director: Manufacturability-Driven Design Lab
Texas A&M University

Introduction

- Response of materials to impact is a very important parameter
- More difficult to design for than most other parameters
- Magnitude, location, and speed of loading all vital considerations
- What opportunities exist for design-for-impact using additive manufacturing?
- Previous work has looked at static problems (yielding, buckling, fracture)
- Using AM: DFAM vs DFWM



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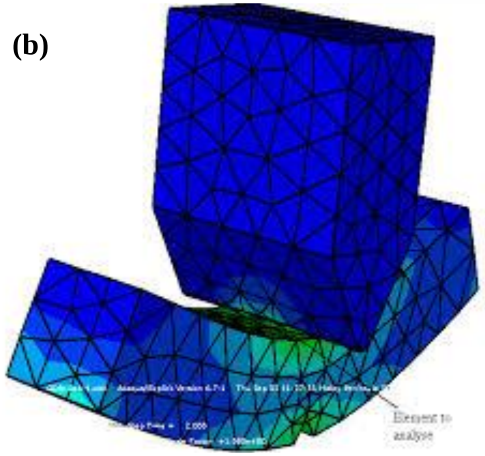

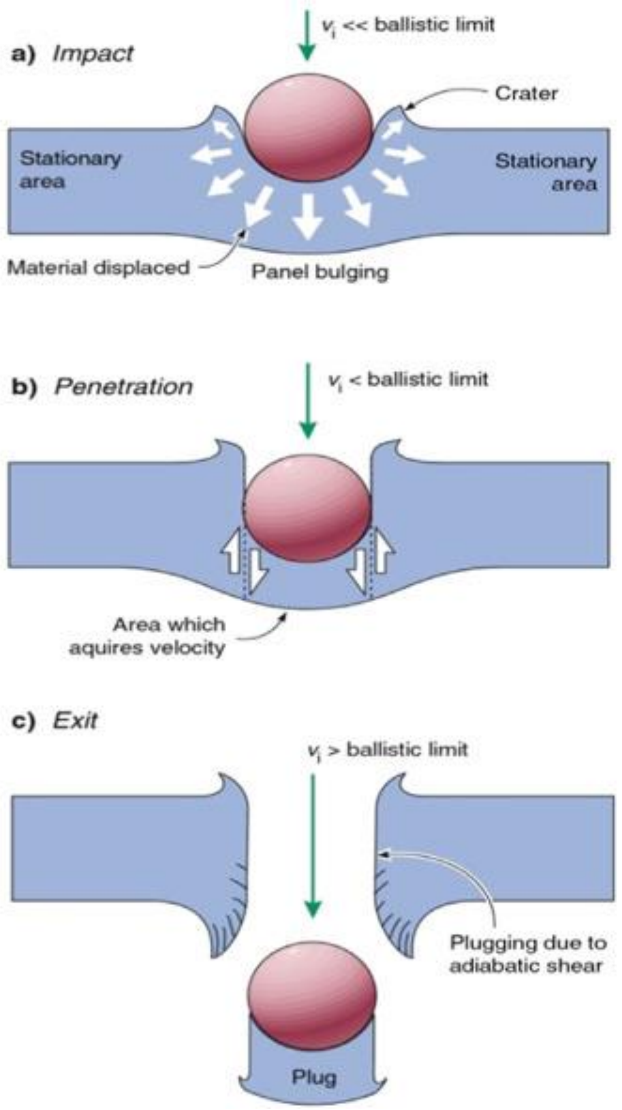

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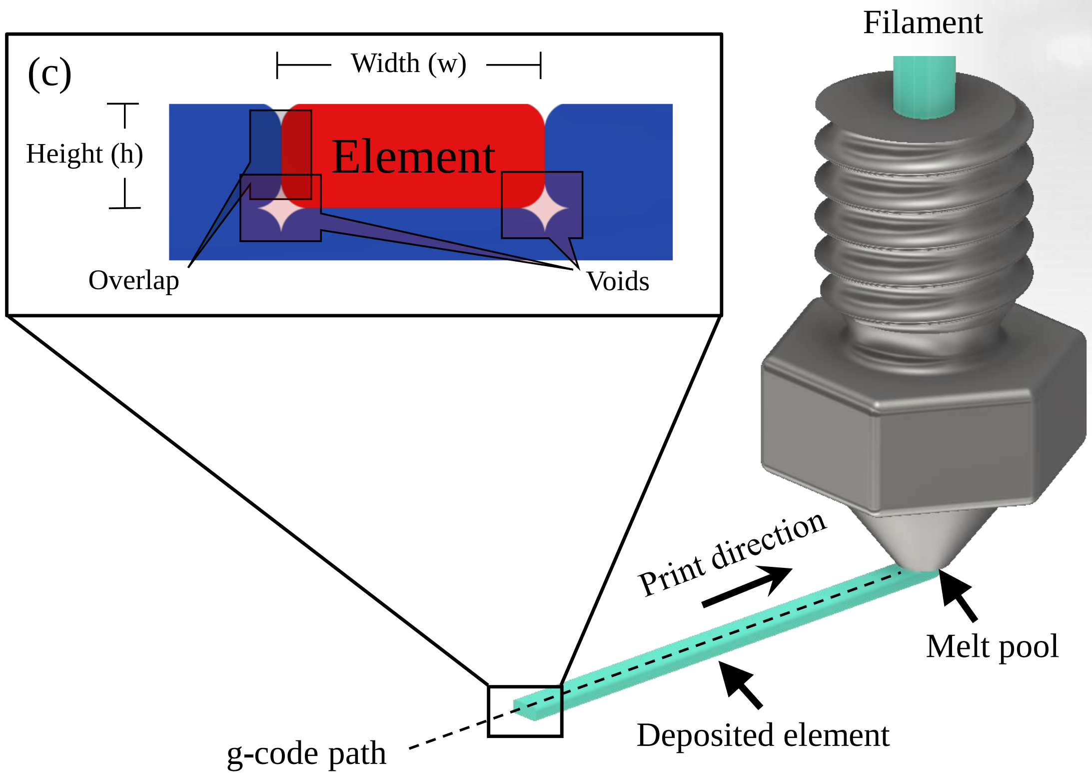
High-Density Extrusion-Based AM

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G1 F750 X68.421 Y96.615 E0.02275
G1 X68.932 Y96.419 E0.0455
G1 X69.466 Y96.3 E0.06825
G1 X69.895 Y96.262 E0.08615
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G1 X70.299 Y96.251 E0.10296
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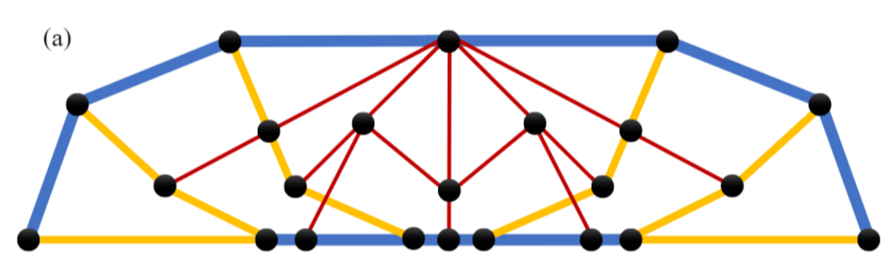

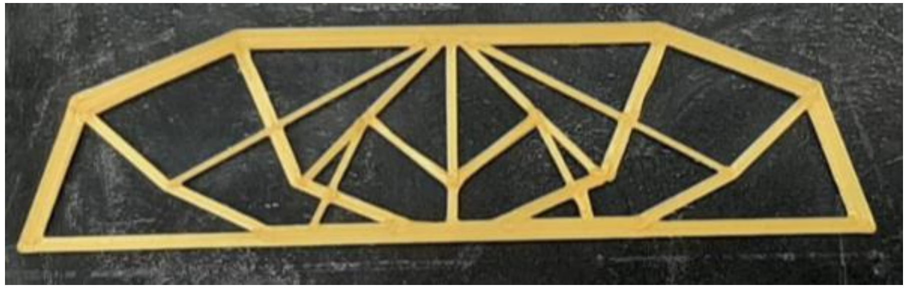

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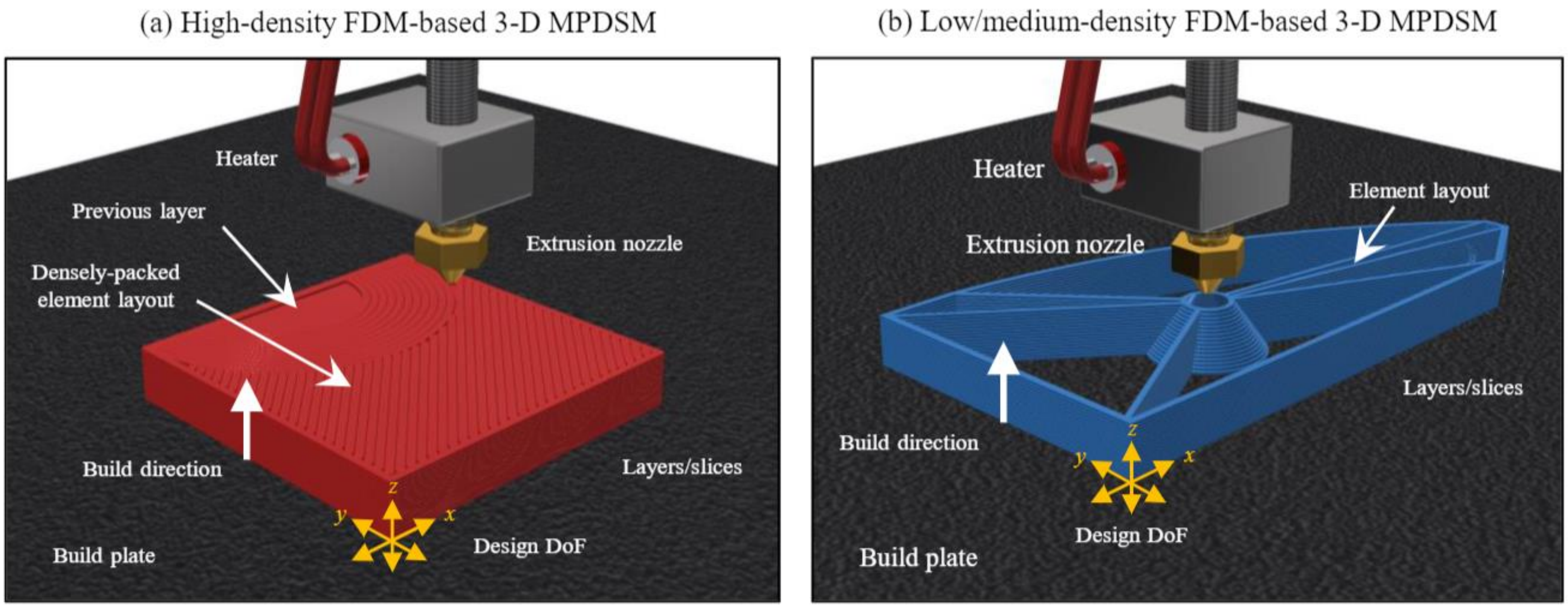
Design-Manufacturing Coupling



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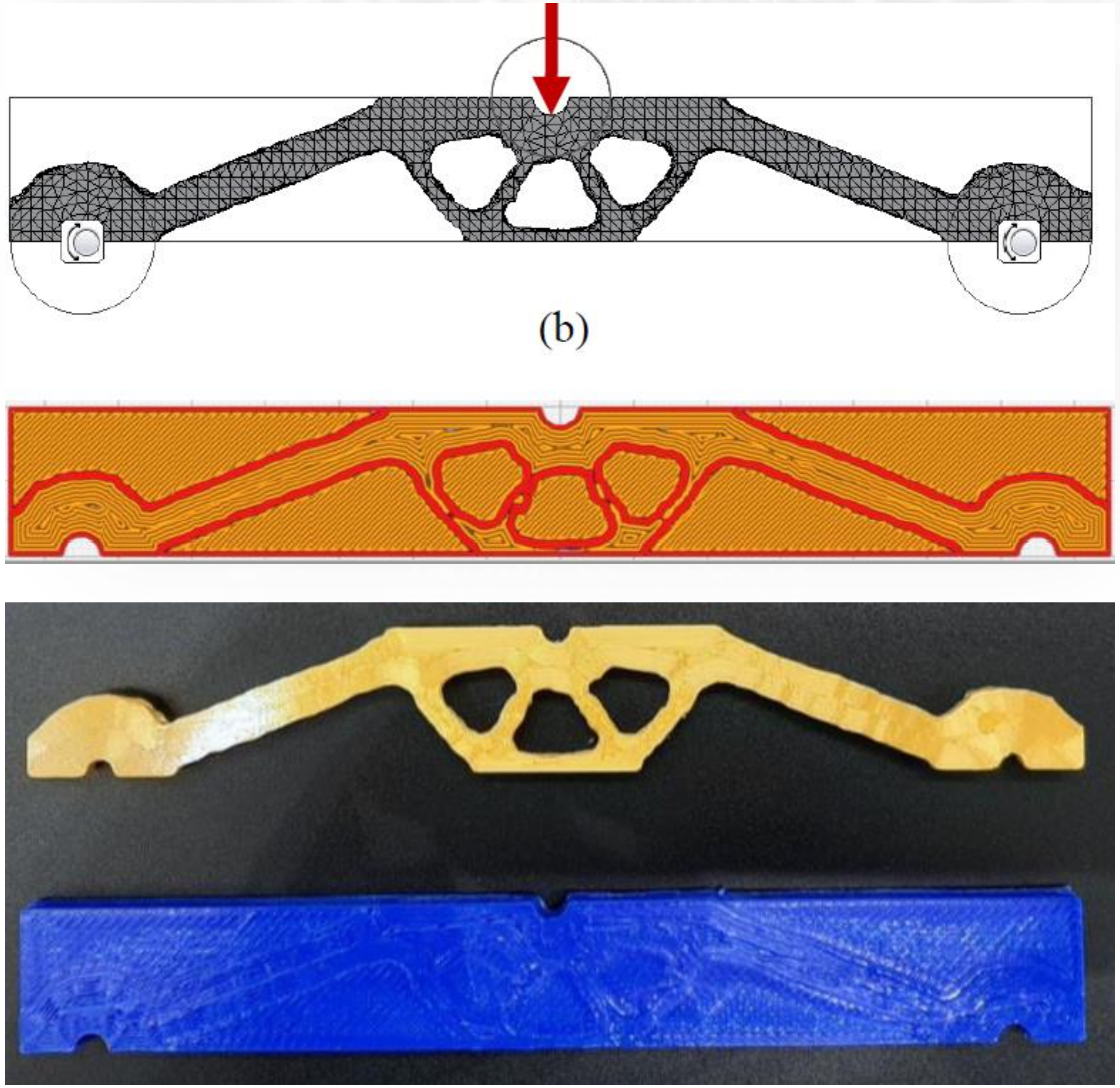
Problem Overview

- Goal: Lay out material elements like a truss/beam problem
- Take advantage of coupling between design and manufacturing
- Reacting to impact loading
- Define designed and raw regions in the material
- 2-D, 2.5D, and 3D solutions
- Objectives: Toughening, embrittling, rate/pattern
- Some work in this area has been done for static fracture problems



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Design Objectives

Toughening: The most common general design objective, where the goal is to make a material, structure, or system as resistant or resilient as possible under an impact load [Fekete et al., 2021].

- A car bumper, a shock absorber, or tool that sees regular impact loads (hammer, axe, pneumatic impact wrench).
- Increasing metal-like properties

Embrittling: It can be useful to increase the brittleness of a ductile material or part in order to make it more useful for some high strain rate applications [Forquin, 2017], such as those often seen in civil engineering and military applications.

- Body armor, bullet-proof windows, and other ballistic impact applications, high-frequency vibration and shock absorbers, and exploding bolts and other quick-release applications.
- Increasing ceramic-like properties

Design Objectives

Tuning for location or path: Tuning the layout of an FDM/FFF-processed material to steer a break or crack to a particular location or along a particular path [Gregoire et al., 2009] has many applications for hybrid manufacturing and in medical and aerospace applications where energy needs to be dissipated at specific locations or paths.

Tuning for rate or threshold: Tuning the layout of these materials to break or crack under an impact load at a specific rate or threshold could be very useful for applications requiring energy flow or dissipation at a specific rate or up to a specific value [Hameed et al., 2020]. Practical applications of this could be for the design of sacrificial shock absorbers and overload prevention systems (e.g., shear bolts, shaft keys, and similar).

Design Approaches and Automation

Manual design

- Parameter control: Direct control of the parameters based on user experience or historical practices
- Manual element layout: Direct control of the layout using expert intuition or historical practices
- Printing orientation: Orienting the part according to expert intuition or historical practice

Design automation

- Parameter optimization: Designed experiments or numerical methods for parameter optimization
- Parametric layout design: Element layout according to a set of parameters
- Stress/strain field layout design: Element layout along the contours of a stress or strain field
- Mathematical layout design
  - Primitives: Element layout according to primitive shapes (triangles, squares, circles)
  - Minimal surfaces: Element layout using mathematical minimal surfaces
- Automated layout design
  - Element optimization: Element layout and orientation using an optimization algorithm
  - Shape optimization: Element layout and orientation using a shape optimization algorithm

Conclusion and Closing Remarks

- As explored in this presentation, numerous different approaches and objectives can be followed to apply AM to impact problems
- Many of the same ideas as previous work for fracture and yielding problems but with very high loading rate
- This discussion primarily applied to thermoplastic polymers
- Other applications for composite materials and other scanning-type AM processes
  - Metal fused filament fabrication (MF^3)
  - Laser powder bed fusion
  - Vat photopolymerization
- Mechanical testing methods and approaches
- Standards and consistent reporting

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