Energetic Material Additive Manufacturing

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REVIEW: TRADITIONAL MANUFACTURING OF EXPLOSIVES

The current “state-of-the-art”
Cast-Cure Process

- Cast-Cure
  - Composite materials
    - Polymeric Binders
    - Explosives
    - Metal Fuels
    - Oxidizers
    - Curatives, Catalysts, Bonding Agents…
    - Plasticizers, Antioxidants, Stabilizers…
    - Processing Aids, Ballistic Modifiers
Melt-Cast Process

- Melt-Cast
  - Purse explosive melted in steam jacketed kettle
  - Charges are loaded by one of three main techniques:
    - Straight pour
    - Pellet Load
    - Riser Load
Pressed Powder Process

- Pressed Powders
  - Produce a “molding” powder
    - Explosive Molecules
    - Wax or Plastic Binder
    - Solvent
  - Press the powder into require shape or into case
Problems with Traditional Manufacturing of Explosives

- **Cast-Cure**
  - Settling of ingredients
  - Poor bonding of cast material to casing
  - Shrinkage and cracking

- **Melt-Cast**
  - Shrinkage and cracking
  - Irreversible growth
  - TNT based explosives are poor in cook-off scenarios

- **Pressed**
  - Not suitable for very large munitions
  - Not suitable for munitions with limited access, internal plumbing, unusual shapes
Need for Disruptive Technologies

- Traditional explosive manufacturing
  - Formulations limited to production via:
    - Cast-Cure
    - Melt-Cast
    - Pressed Powders
  - Limited set of ingredients.
  - Feedstock sources limited, often single vendor or foreign sourced
- Improvements to existing technologies
  - Often incremental only, difficult/costly to update large scale manufacturing plants
  - Limited impact on performance or munition safety

5”/58 Projectile Showing Incremental Pressing of Explosive Fill
Need for Disruptive Technologies

- After 100 years of explosive molecule synthesis efforts...
  - We have 2x TNT with a significant cost increase per pound
  - CL-20, the top molecule, is qualified in only one DoD formulation
    - CL-20 adoption is held back by
      - Money/Time to redevelop formulations for existing systems
      - Lack of production of the molecule (economy of scale).
  - The one formulation...? An explosive ink used in 3D printing of fuzes.
Introducing Additive Manufacturing (AM)

- Additive Manufacturing, a working definition
  - A general term that encompasses several technologies that can create 3D objects by adding material layer by layer

- General Benefits
  - Cost Savings
  - Material Control
  - Rapid Prototyping
Why Energetic Material AM?

• Cost Savings
  – AM cost per part insensitive to number of parts produced

![Cost per Part Comparison Graph]

Figure 7 - Comparison of several AM methods to Injection Molding - Rapid Manufacturing Research Group at Loughborough University (UK) Study

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Why Energetic Material AM?

- Precision Placement of Materials
  - Unique structures not obtainable by traditional means
  - Reduced waste

http://www.nanoscribe.de/en/technology/additive-manufacturing/
Why Energetic Material AM?

- Composition/Density Control
  - Gradients can produce unique explosive effects
  - Detonation Merging, multi-point initiation “baked in”, insensitivity, etc.

**Radially Density Graded Energetic**

Lower Density

Higher Density

**Compositional Gradients**

*Fig. 5. A finite element model showing elastic mismatch in two dissimilar metal automobile valve stems at 1000 K. The figure on the left shows a valve with a 304L stainless steel stem connected to an Inconel 625 valve via a 2.5 cm long gradient of composition. On the right, the gradient is replaced with a friction weld. The stress at the joint of the friction welded part has an approximately ten times higher stress than the compositionally graded alloy.*

Why Energetic Material AM?

• Rapid Prototyping
  – Reduce time between design and a working prototype
  – Can incorporate cost savings and material controls

http://www.bresslergroup.com/blog/rapid-prototyping-for-user-research/
Technology Gap: Polymer Solutions

• Gap
  – Compatibility of existing energetics with current feedstock for material extruded systems
• Need to develop AM compatible melt-castable and cast-curable energetic binders for usage in Extruder 3D printers

We need to expand upon the very limited list of thermal plastics/polymers to produce energetic materials
Near Term R&D Efforts at IHEODTD

• AM compatible binders
  – Leverage existing programs to acquire COTS material extruder style printer
  – Survey existing melt/cure-castable binders for use in energetic formulations
  – Demonstrate AM compatibility with promising binders with and without inert simulant
  – Develop Safe handling procedures
  – Produce small-scale explosive test samples with down-selected binder in 3-D printer
  – Identified academic partners already making good progress in these areas

• Functional Graded Materials
  – Leverage existing programs to acquire COTS, multi-nozzle, material (ink) jet printer
    • select promising formulations that would be applicable to density and compositional grading – ex. Lakehurst fire suppression
  – Demonstrate Successful FGM characteristics and microstructural control
AM printed PBX Simulants

- AM Produced PBX Simulant
  - R45M Binder (HTPB based)
  - 88% bi-modal sized solids loading
  - Produced in collaboration with SDSMT
QUESTIONS?
Back-up Slides
AM Technologies

• **Material Extrusion**
  
  – Material selectively dispensed through a nozzle
  
  – Inexpensive, most common AM technology
  
  – Resolution limited by nozzle radius

Most Common Form:

– Fused Deposition Modeling (FDM)
  
  • Plastic or metal filaments as feedstock.
  
  • Many commercial vendors
    
    – Stratsys, 3DSystems, etc.
  
  • Used at the CRIP
  
  • Requires post processing
AM Technologies

• Material Jetting
  – Photopolymer droplets selectively deposited and UV cured
  – Multiple print heads can simultaneously produces multiple materials in final product
    • PolyJet Connex3 system has 82 Heads for 82 different materials.
  – High accuracy and resolution
  – Limited to photopolymers and some waxes

Source: Loughborough Univ. AM Research Group
AM Technologies

- **Binder Jetting**
  - Liquid binder is selectively deposited to bind powder/granular materials into a structure.
  - Wide range of materials: metals, powders, and ceramics
  - High speed, but not good for structural parts
  - Post-processing required for hardening

- [Example of Binder Jetting](#)
AM Technologies

• Powder Bed Fusion
  – Thermal energy selectively fuses regions of a powder bed
  – Uses a laser or electron beam
  – Can use metals or polymer powders
  – Inexpensive, but slow

  – Examples
    • Direct Metal Laser Sintering (DMLS)
    • Electron Beam Melting (EBM)
    • Selective Heat Sintering (SHS)
    • Selective Laser Melting (SLM)
    • Selective Laser Sintering (SLS)

Source: Loughborough Univ. AM Research Group
AM Technologies

• Vat Photopolymerization
  – Liquid Photopolymer in a vat is selectively cured by light
  – High print accuracy
  – Fast
  – Limited material range (photo-resins)

  – Novel: Continuous Liquid Interface Production (CLIP)
    • CLIP Video

Source: Loughborough Univ. AM Research Group

Continuous Liquid Interface Production

Source: Carbon3D
Other AM Technologies

- Directed Energy Deposition
  - Thermal energy fuses materials by melting as they are being deposited
  - Limited to metals

- Sheet Lamination
  - Sheets of material bonded to form an object.
  - Limited to Paper, Plastics, some sheet metals

Source: Loughborough Univ. AM Research Group