U.S. ARMY

DEVCOM ARMAMENTS CENTER

JUGGERBOT3D

EMERGING DIRECT INK WRITE CAPABILITIES FOR FUNCTIONAL SOFT MATTER APPLICATIONS

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DECEMBER 2023

	DEVCOM Armaments Center
	FCDD-ACM-EW
	NONE
	A
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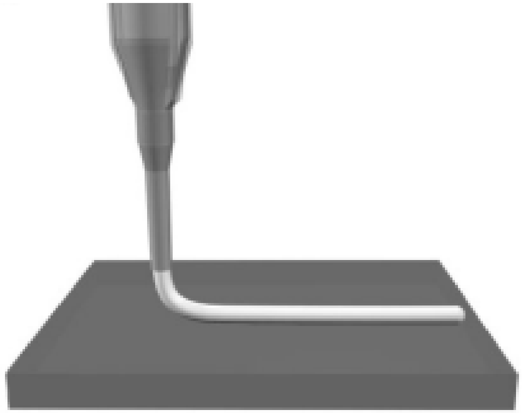
[2] PRESIDENT | JUGGERBOT 3D LLC

OUTLINE

1. INTRODUCTION
2. VISION
3. ASSESSMENT
4. SELECT APPLICATIONS
5. CONCLUSION

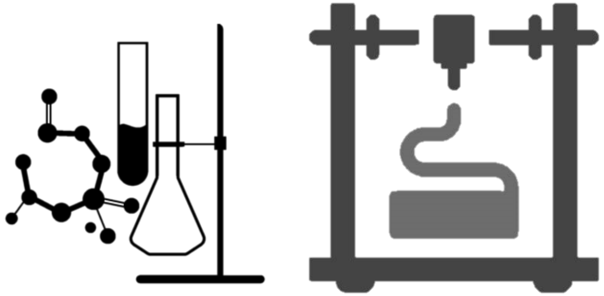


DIW is an underappreciated and underutilized AM mode

Enables advanced engineering materials

Rapidly gaining technical and manufacturing maturity

Should be considered as part of manufacturing strategy



OFF THE BENCH

INDUSTRIAL TRANSITION

VISION: STRATEGIC ALIGNMENT

PRIORITY RESEARCH AREAS

Material by Design
Science of Additive Manufacturing

Distribution Statement A: Approved for public release. DOPSR case #21-S-0711 applies. Distribution is unlimited.

Department of Defense Additive Manufacturing Strategy

January 2021

Joint Defense Manufacturing Council

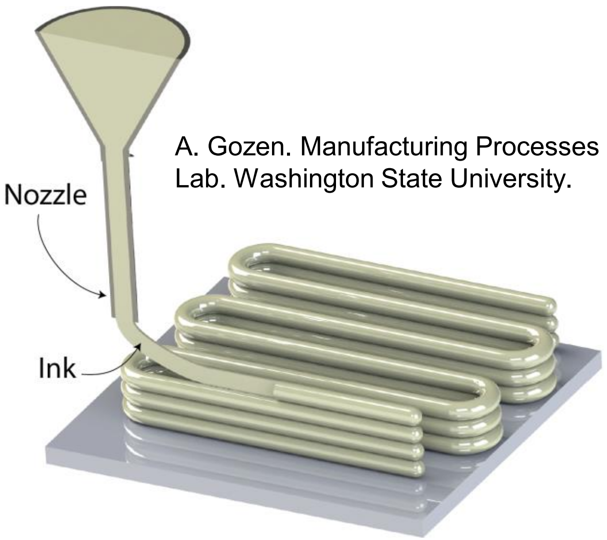
GOAL 1: ***Integrate*** AM into DoD and the ***defense industrial base.***
GOAL 2: ***Align*** AM activities across DoD and ***external partners***.
GOAL 3: ***Advance*** and Promote ***Agile Use of AM***.
GOAL 4: Expand proficiency in AM: ***learn, practice and share.***
GOAL 5: Secure the AM workflow.

Washington, D.C.

INTRO: DIRECT INK WRITE

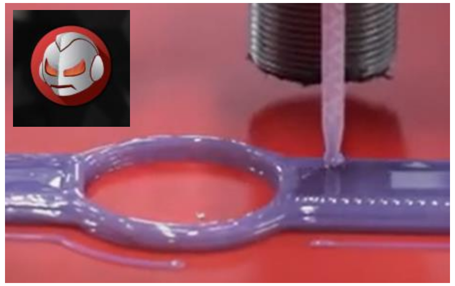
Direct Ink Write (DIW): extrusion-based additive manufacturing method. A liquid-phase “ink” is dispensed out of nozzles under controlled flow rates and selectively deposited along digitally defined paths to fabricate 3D structures layer-by-layer.

- ***Conceptually Simple***
  Cake icing
- ***Advantages over FFF***
  Material versatility (thermosets, elastomers)
  Ink tailorability (multiscale functionality)
- ***Wide range of engineering materials + applications***
  Food, pharmaceuticals, ceramics, synthetic biomaterials, construction, energy, and defense
- ***Maturing research & Industrial base***

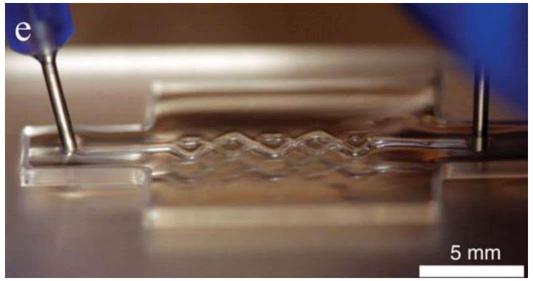


A. Gozen. Manufacturing Processes and Machinery Lab. Washington State University.

R. Karyappa & M. Hashimoto. Chocolate-based Ink Three-dimensional Printing (Ci3DP). Nature Scientific Reports. 2019.



Juggerbot 3D LLC. Tricks of the Tradesman. The Role of Direct Ink Writing in Industrial 3D Printing. 2021.



D. Kolesy et al. 3D Bioprinting of Vascularized, Heterogeneous Cell-Laden Tissue Constructs. 2014.

U.S. Army Engineer Research and Development Center, Construction Engineer Research Laboratory’s concrete 3D printing apparatus. US Army. 2020.

INTRO: ROBOCASTING

J. Cesarano seminal work in the area circa 1990s

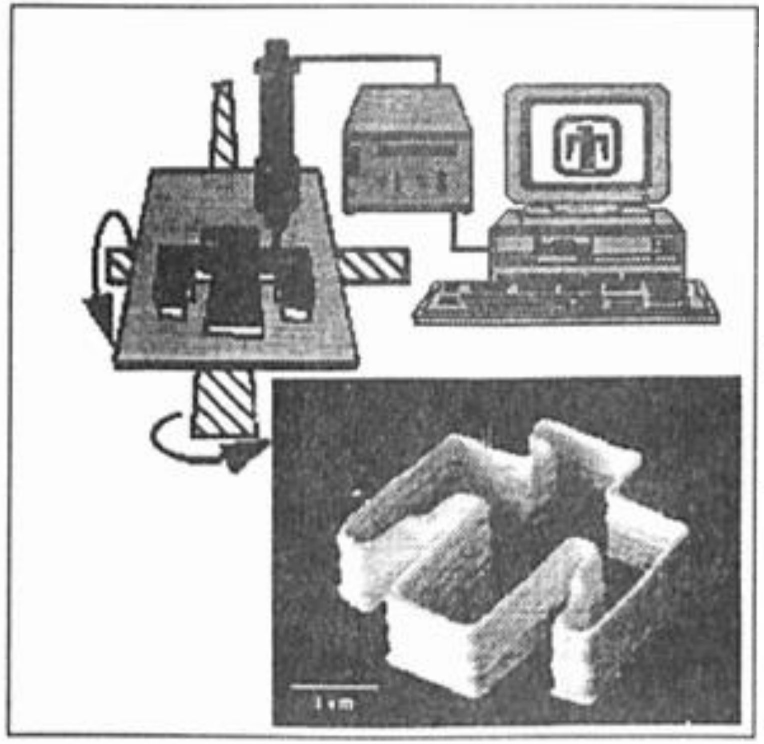


Figure 1. Schematic of the Robocasting process with an inset photo of a thunderbird made with 20 layers of aluminum oxide, and sintered crack-free to 96% of theoretical density.

J. Cesarano & S. Grieco. Robocasting: A New Technique for the Freeform Fabrication of Near-Net-Shape Ceramics. Materials Technology. 1997.

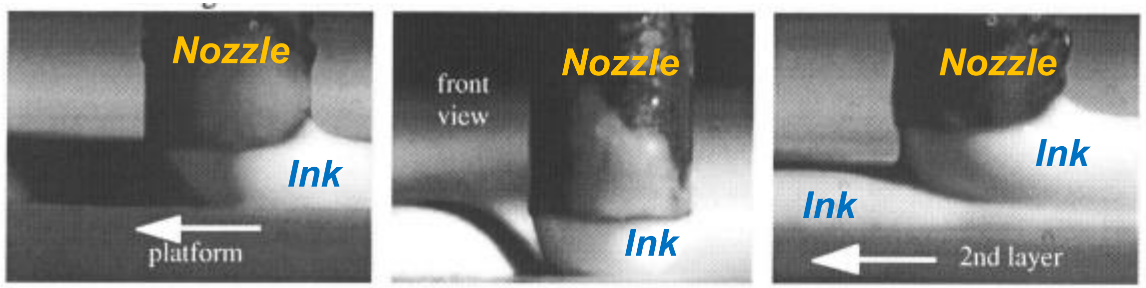
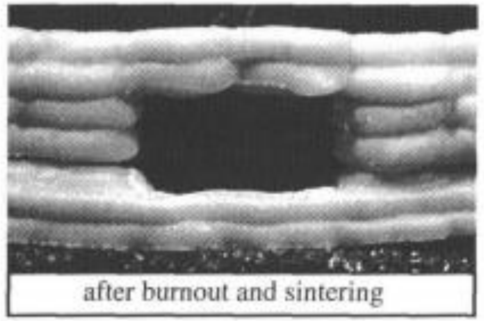


Figure 3: Images of an alumina slurry being deposited onto a moving platform (left and center) and the slurry being deposited onto a previously deposited alumina bead (right).



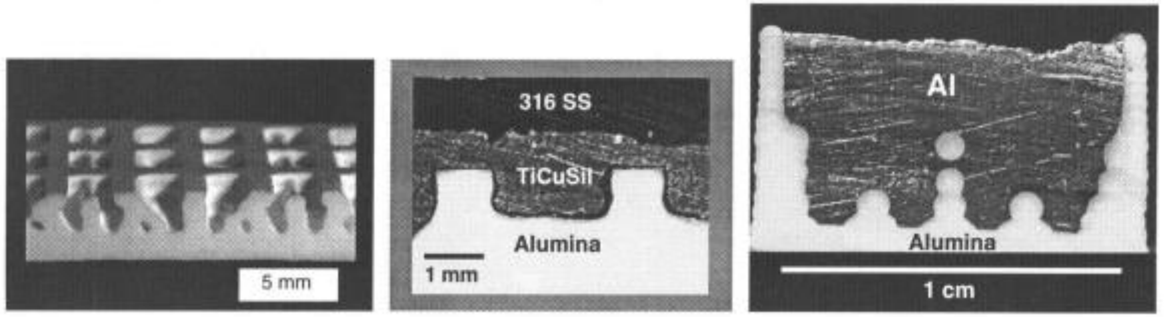


Figure 4: Robocast alumina preforms infiltrated with metal form graded interlocking composites.

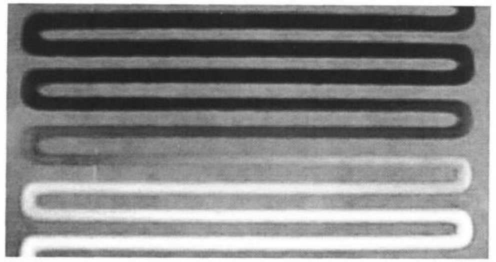


Figure 6: Demonstration of a graded transition between two slurries (bead width 1.5 mm).

J. Cesarano. A review of robocasting technology. Materials Research Society. 1999.

INDUSTRIAL 3D PRINTERS FOR PRODUCTION MATERIALS AT SCALE

Large format 3D printers delivering performance, reliability and value.

Committed to guiding the additive manufacturing industry toward a more sustainable tomorrow.

Pellet Specialty

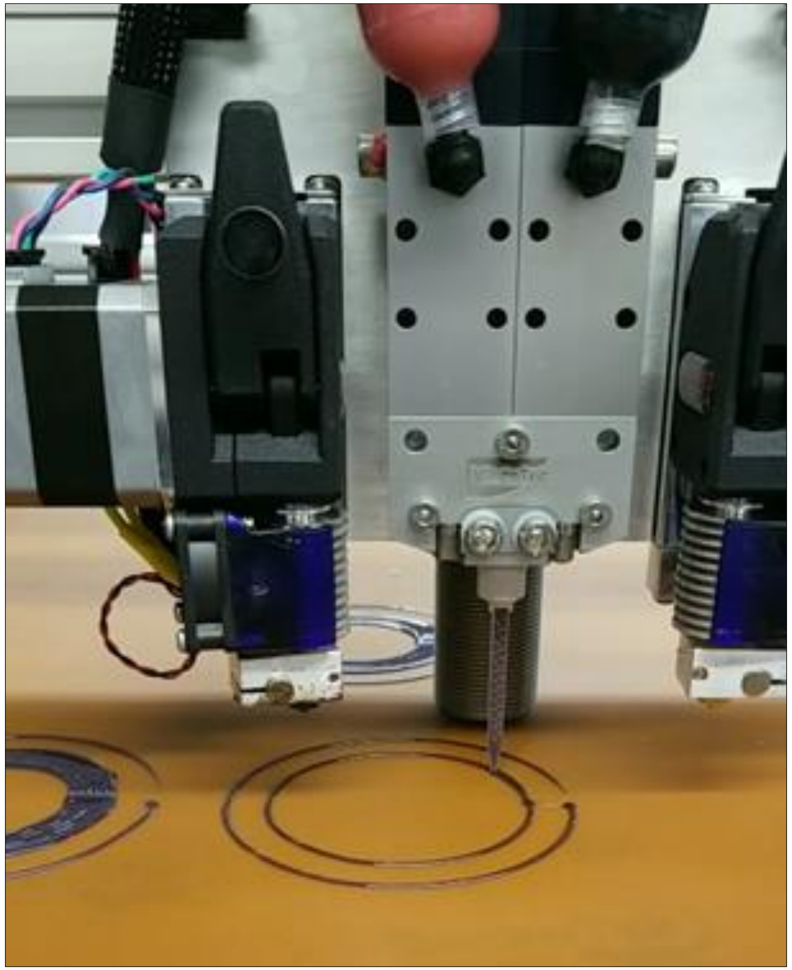
Various grades of available thermoplastic materials for FGF printing

- *Standard: ABS, ASA, PE, PP*
- *Engineering: PA, PC, PET*
- *Performance: PEI, PEEK, PSU*

DIW Development

<u>Ink Extrusion System:</u>

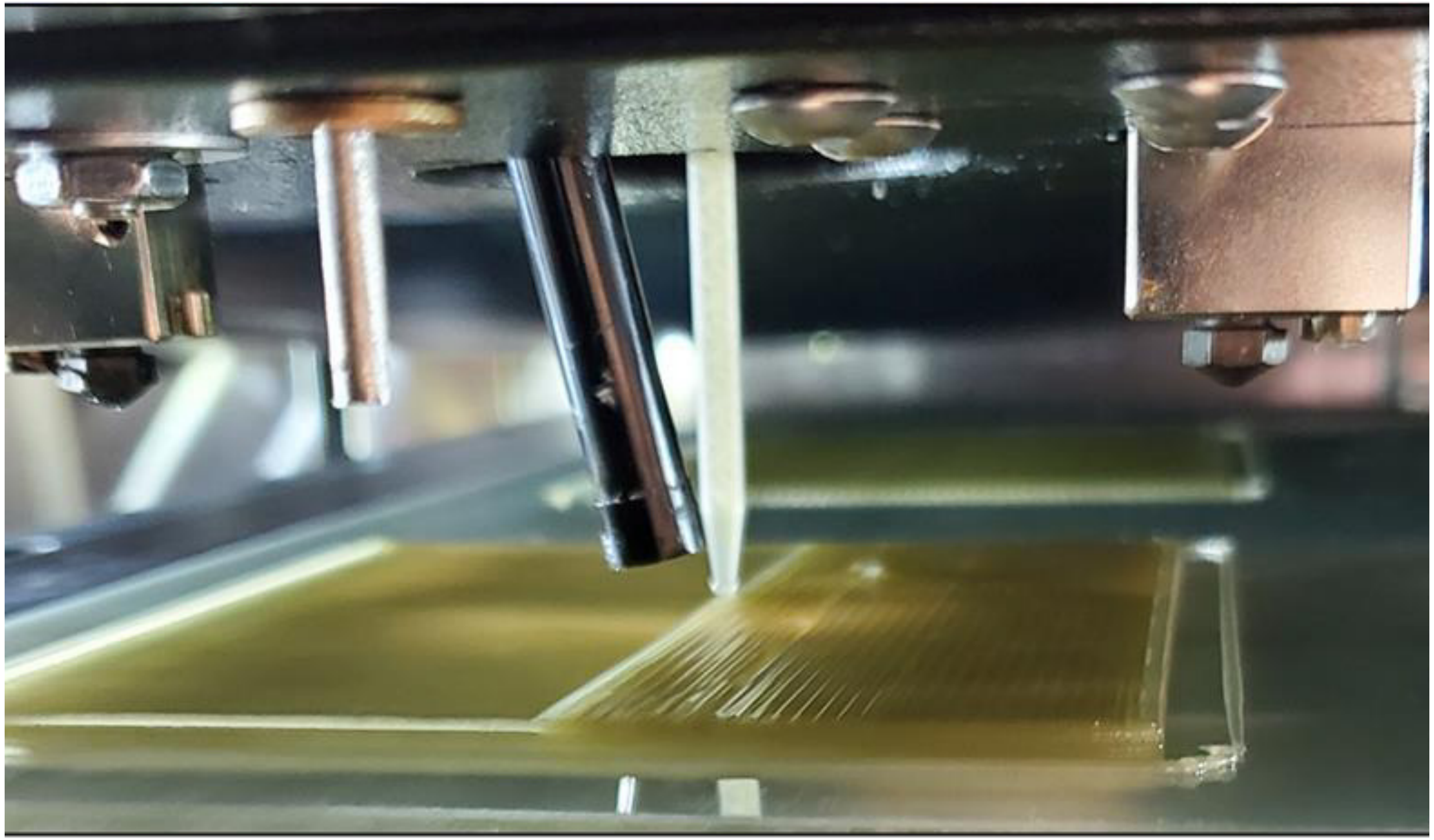
- Volumetric dispenser and filling system
- Two servo motors for Part A and Part B resin that directly drives mixing screws (rotors).
- Mixing screws encapsulated in a stator membrane, which allows the resin ink material to “pump” and be conveyed through an aluminum manifold.
- Manifold is designed to allow the materials to flow separately through individual 45° channels.
- Static mixer joins the two materials (A & B resins) and deposits/volumetrically dispenses the new mixture through a fixture orifice.



DIW - Functional Materials

<u>Anhydride epoxy</u> formulations processed through Tradesman Series™ F3-32-H additive system.

- Latent thermal cure behavior
- Thixotropic viscosity
- Demonstrated Speeds: 5mm/s – 20mm/s

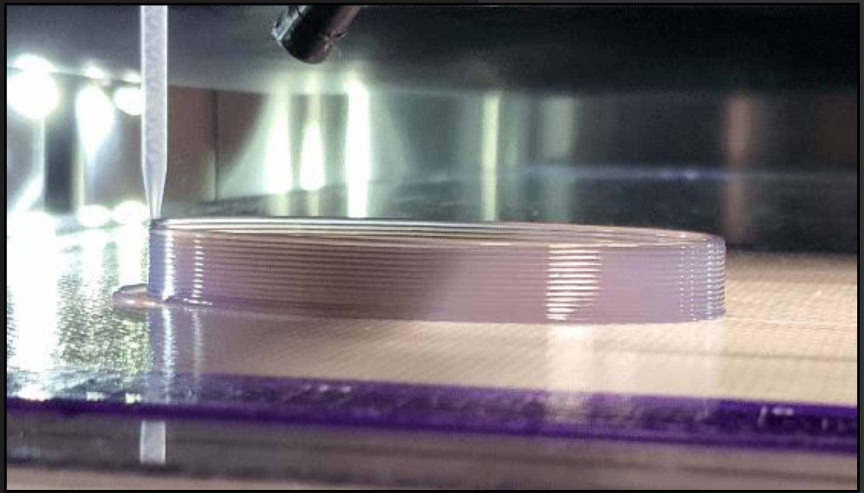


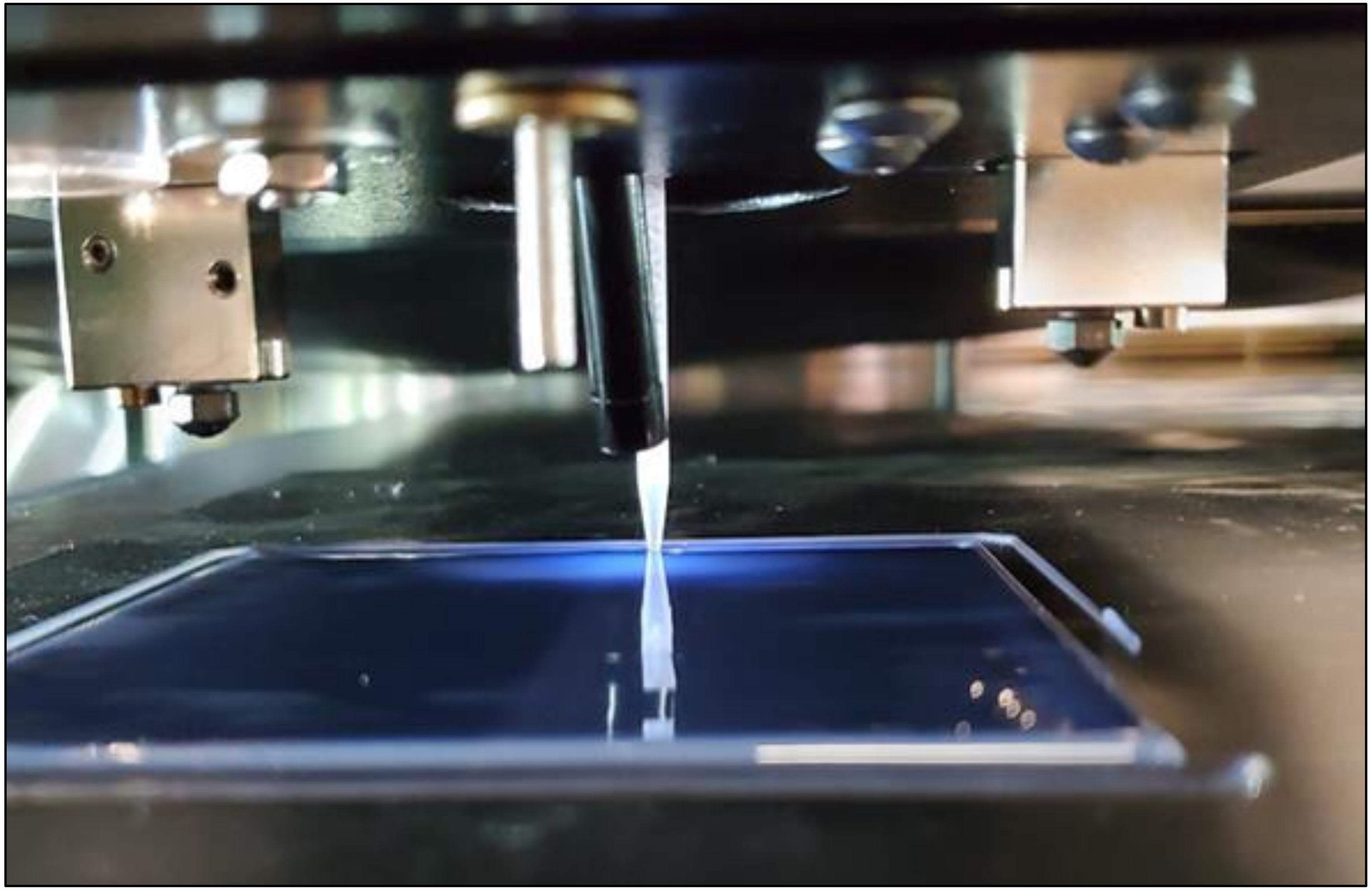
Army STTR Phase 1
Topic#: A20B-T010-0326
Project Title: Direct Ink Writing of Functionally Graded Thermoset Materials

DIW - Functional Materials

Polyurethane formulations processed through Tradesman Series™ F3-32-H additive system;

- 30-45 Gelation activity
- Demonstrated Speeds: 5mm/s – 20mm/s
- Prevention of curing of materials within the static mixer required





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Army STTR Phase 1

Topic#: A20B-T010-0326

Project Title: Direct Ink Writing of Functionally Graded Thermoset Materials

JUGGERBOT3D

PennState Behrend

Chromatic 3D Materials

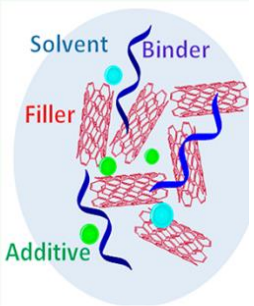
X-LINK3D

BDI ADDITIVE

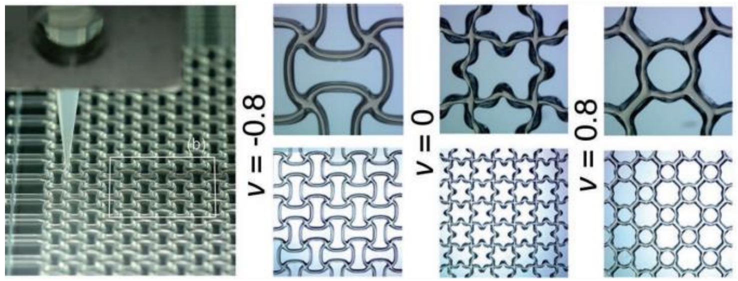
VISION: ARCHITECTED FUNCTIONAL SOFT MATTER

AM promise: **ability *to* *locally specify both composition and structure* will allow tailored control over material properties and functionality**

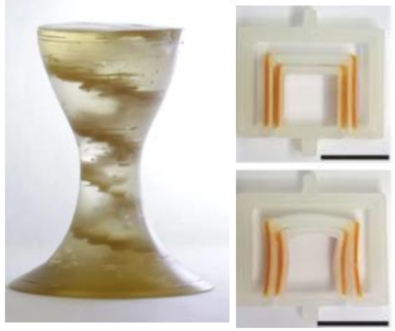
- **Microstructure (ink):**
- **Mesostructure (layer):**
- **Macrostructure (part):**
- **Multi-material, graded, heterogeneity**



Y. Zhang et al. Recent Progress of Direct Ink Writing of Electronic Components for Advanced Wearable Devices. ACS Applied Electronic Materials. 2019.



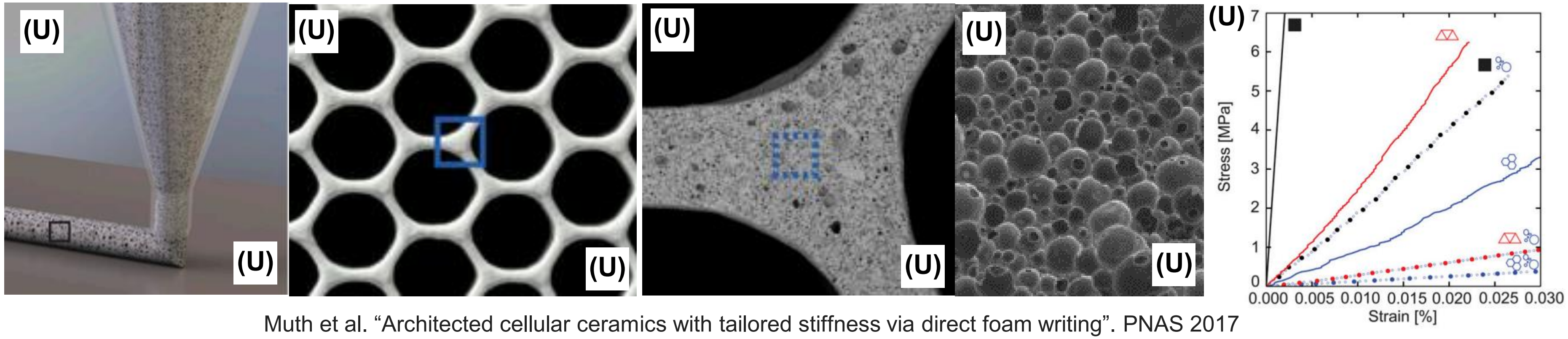
A. Clausen et al. Topology Optimized Architectures with Programmable Poisson’s Ratio over Large Deformations. Advanced Materials. 2015



D. Kokkinis et al. Multimaterial magnetically assisted 3D printing of composite materials. Nature Comunications 2015.

- **This ultimately leads to metamaterials and “4D” printing**

PROCESS ***STRUCTURE*** ***PROPERTY***



Muth et al. “Architected cellular ceramics with tailored stiffness via direct foam writing”. PNAS 2017

PERFORMANCE

Self healing
Shape shifting
Reactive
Drug delivery
Specific strength
Toughness
Magnetic
Piezoelectric
Dielectric

SOME EMERGING APPLICATIONS

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FLEXIBLE SENSING

NATIONAL DEFENSE SCIENCE & TECHNOLOGY STRATEGY 2023

Microelectronics

Integrated Sensing & Cyber

X. Liu et al. 3D Printing of Living Responsive Materials and Devices. Advanced Materials. 2017.

BIOTECH

NATIONAL DEFENSE SCIENCE & TECHNOLOGY STRATEGY 2023

Biotechnology

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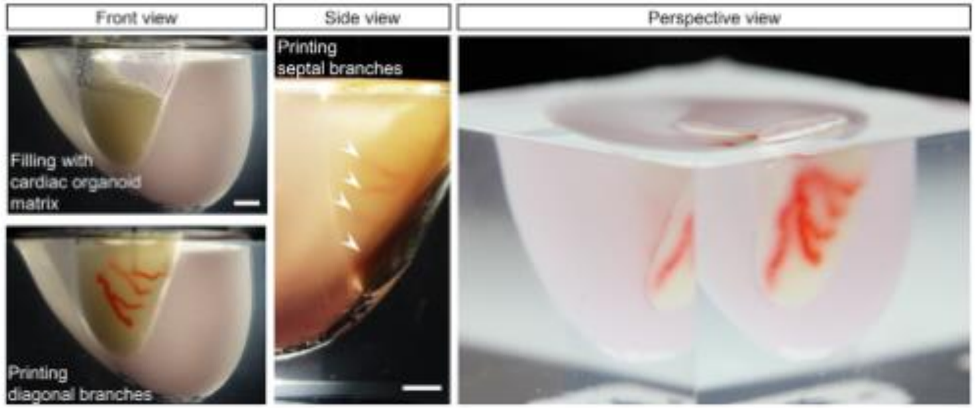
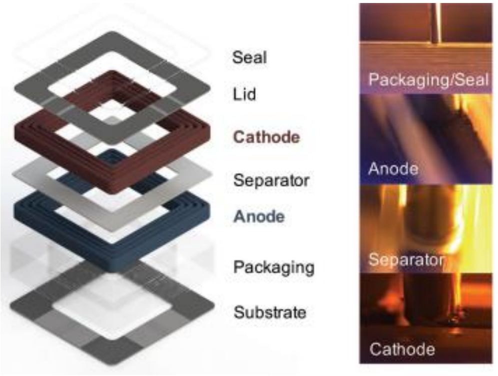


M. Skylar-Scott et al. Biomanufacturing of organ-specific tissues with high cellular density and embedded vascular channels. SCIENCE ADVANCES. 2019.

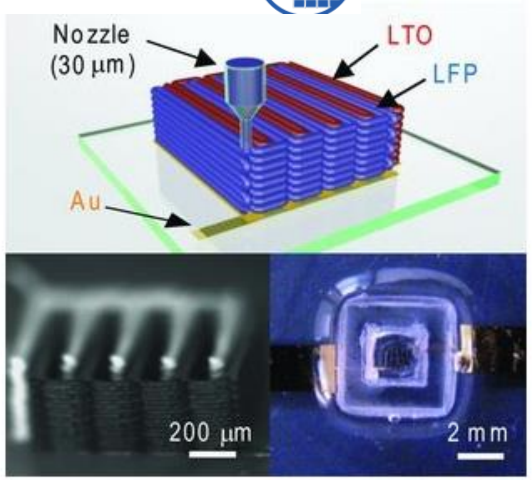
ENERGY

NATIONAL DEFENSE SCIENCE & TECHNOLOGY STRATEGY 2023

Renewable Energy Generation & Storage



T-S Wei et al. 3D Printing of Customized Li-Ion Batteries with Thick Electrodes. Advanced Materials. 2018



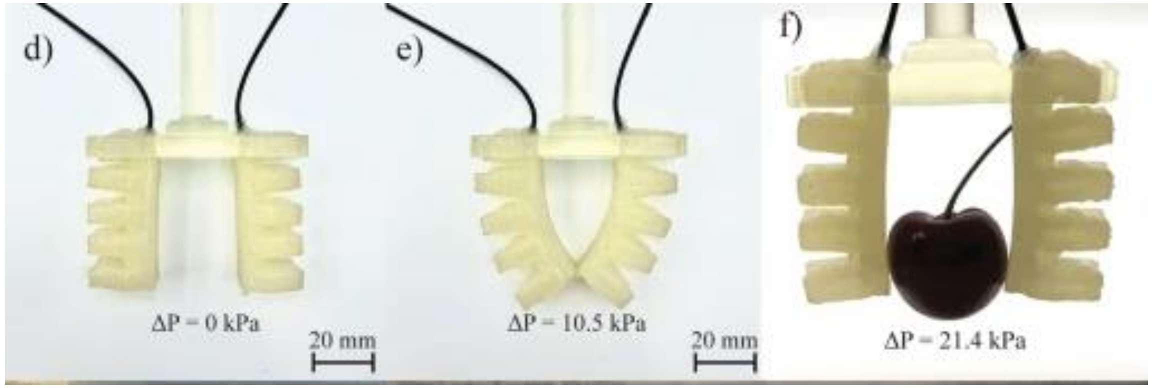
K. Sun et al. 3D Printing of Interdigitated Li-Ion Microbattery Architectures. Advanced Materials. 2013.

SOFT ROBOTICS

NATIONAL DEFENSE SCIENCE & TECHNOLOGY STRATEGY 2023

Trusted AI & Autonomy

Human Machine Interfaces



O.D. Yirmibesoglu. Multi-material direct ink writing of photocurable elastomeric foams. Communications Materials. 2021.

APPLICATION: BATTERIES AND ELECTRONICS

WHO: *DOE Nat'l Lab w/ Large Biz Partner*

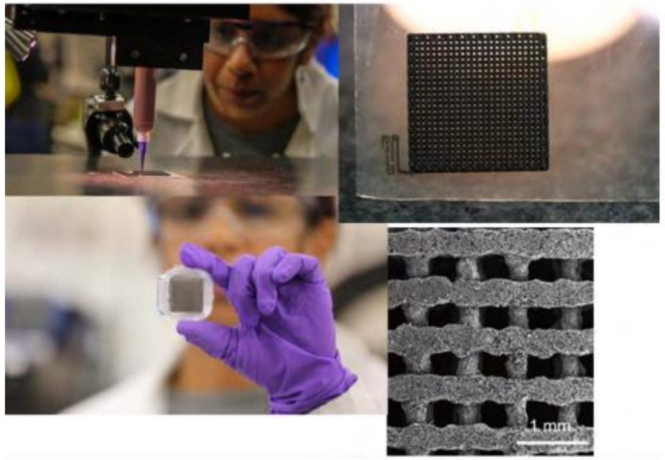
Lawrence Livermore National Laboratory

MilliporeSigma

[2022]

WHAT: *Energy Inks*

Enables customized devices from batteries, catalysts, and fuel cells to heat exchangers and desalination devices, among others



HOW: *Functional DIW feedstocks*

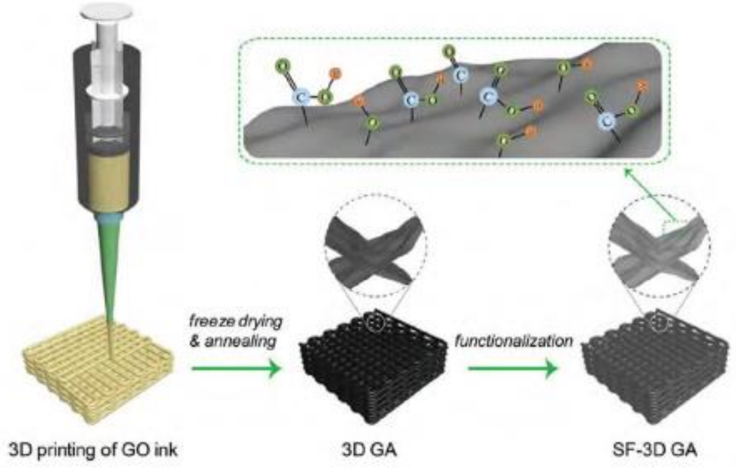


Figure 6: Steps for 3D printing of graphene oxide ink

WHY:

- *Improved time to market*
- *Improved productivity (↓ cost, time)*
- *Customizable*
- *Higher performance*
- *Survivable*
- *Advantages vs. powder AM, inkjet, and traditional mfg*

GROWING GLOBAL DEMAND FOR ELECTRONICS, ENERGY STORAGE DEVICES, AND CLEAN ENERGY TECHNOLOGIES

APPLICATION: GASKETS & TOOLING

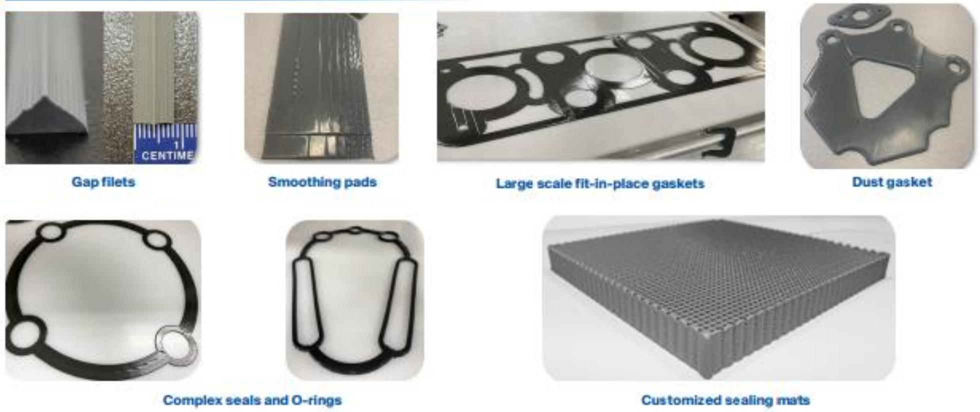
WHO: *Large biz sponsored by US Army*

We protect and beautify the world™

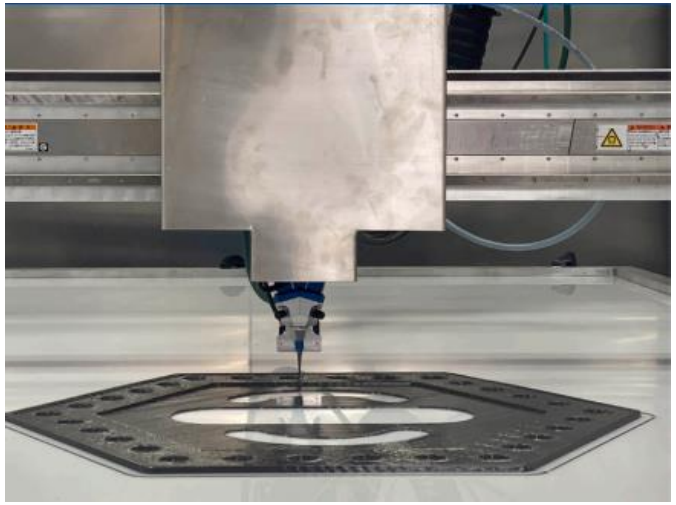
DEVCOM ARMY RESEARCH LABORATORY

[2018-2023]

WHAT: *Aerospace seals*



HOW: *"Ambient Reactive Extrusion"*



WHY:

- *Improved time to market*
- *Improved productivity (↓ cost, time)*
- *Customizable*
- *Point of need mfg*

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Direct Ink Write Applications

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Emerging Direct Ink Write Capabilities for Functional Soft Matter Applications

Robot End Effectors

End of Arm Tooling (EOAT)
Components:
- Soft/Rigid Grippers
- Vacuum/Suction Cups

Material Requirements:
- Nonabrasive
- Wear resistant
- Smooth surface
- Compressive (Soft)
- Chemical resistant
- Light Weight

Applications:
- Manufacturing
- Food
- Healthcare
- Agriculture
- Logistics

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Elastomer Seals and Gaskets

Seals prevent leakages between two moving parts such as shafts, pumps, and engine parts

Gaskets prevent leakages between two flat surfaces of a component or a flange

Material Requirements:

- High-temperature resistance
- Abrasion and shock resistance
- Corrosion and oxidation protection
- Degradation resistance.
- Salt, water, alkaline, and acid resistance
- Thermal or fire insulation.

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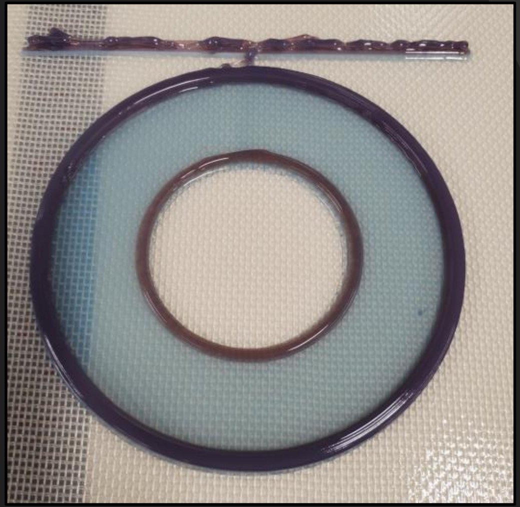
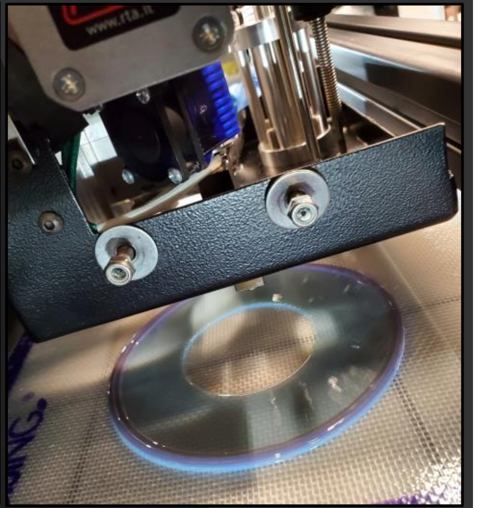
Elastomer Seals and Gaskets

Multi-material components developed using advanced tool path programs, allowing operators to print the initial solid layer with softer materials, then change to a hard material to print edge features.





Multi-Durometer Seal

Thermoset Material: ChromaFlow™50 & ChromaFlow™90

Seal stretches and flex's easily in certain directions but refrains from folding or twisting due to the rigid outside and inside perimeters.

Army STTR Phase 1

Topic#: A20B-T010-0326

Project Title: Direct Ink Writing of Functionally Graded Thermoset Materials

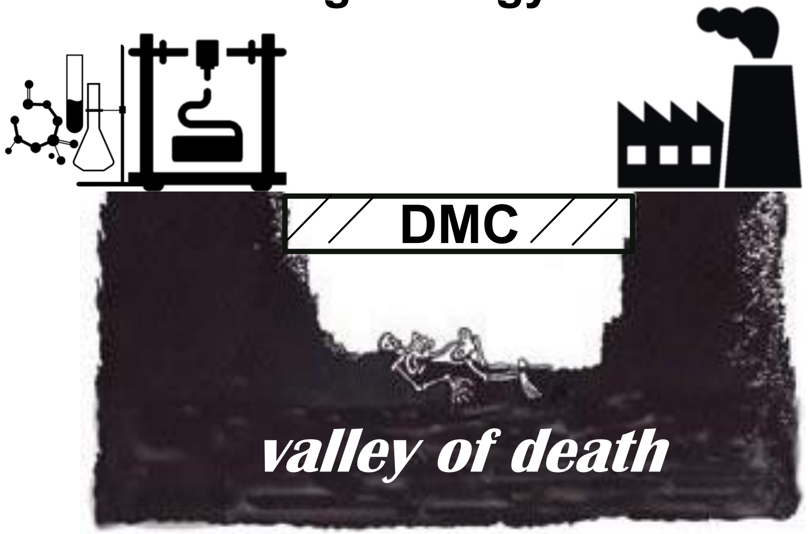
CONCLUSION

DIW is an underappreciated and underutilized AM mode
- There are advantages over traditional means, FFF, and other AM modes
- It's conceptually simple (who hasn't put icing on a cake?)

Enables advanced engineering materials
- AGILITY! TAILORED MULTISCALE FUNCTION!
- Materials by design

Rapidly gaining technical and manufacturing maturity
- Several business have started to offer applied industrial solutions relevant to DoD

Should be considered as part of manufacturing strategy
- Mixed-mode/hybid mfg
- Enabling functions



THANK YOU.

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