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Advancing Molded Fiber Prototyping with Additively Manufactured Tooling

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Introduction to Additive Manufacturing

Additive Manufacturing (AM): Also known as 3D printing, AM is a process in which objects are manufactured layer-by-layer through the selective deposition or *addition* of raw materials. This is the opposite of more traditional manufacturing in which objects are manufactured by selective removal or *subtraction of* material from a large mass of raw material.

Types of Additive Manufacturing: Fused Deposition Modeling (FDM)/Fused Filament Fabrication (FFF), Selective Laser Sintering (SLS), Stereolithography (SLA), Direct Melt Laser Sintering (SMLS), Selective Laser Melting (SLM) are some of the most common.

Common Materials for AM: Thermoplastic filament/pellets/powders, Composite filament/pellets, UV curing resin, thermoset resins, metal powders, ceramic powders, etc.

FDM Applications for Manufacturing: Composite fabrication tooling, robotic end-effectors, temperature-resistant housings, fabrication of jigs and fixtures.

Why focus on FDM/FFF printed tooling: While UMaine also performs research in metal additive manufacturing, the ASCC focuses primarily on thermoplastic FDM/FFF printing because it is **cost-effective**, utilizes **renewable and bio-based raw materials**, and leverages our **extensive R&D in wood-plastic and FRP composites**.

Benefits of Additive Manufactured Tooling

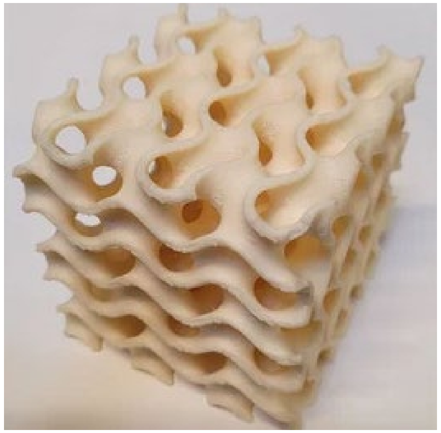
Benefits of AM Tooling:

- Rapid tooling production times
- Cost-effectiveness for short runs and prototypes
- Ability to create complex geometries
- Customization and design flexibility
- Material optimization (lighter tools)
- Sustainability (less scrap & landfilling)

Benefits of Thermoformed Molded Fiber products:

- Reduced Time to Market (TTM) for parts
- Durable Material Options
- Customizability (heating/cooling, sensors, porosity, metal cladding, lattice structures)
- Recyclable/sustainable

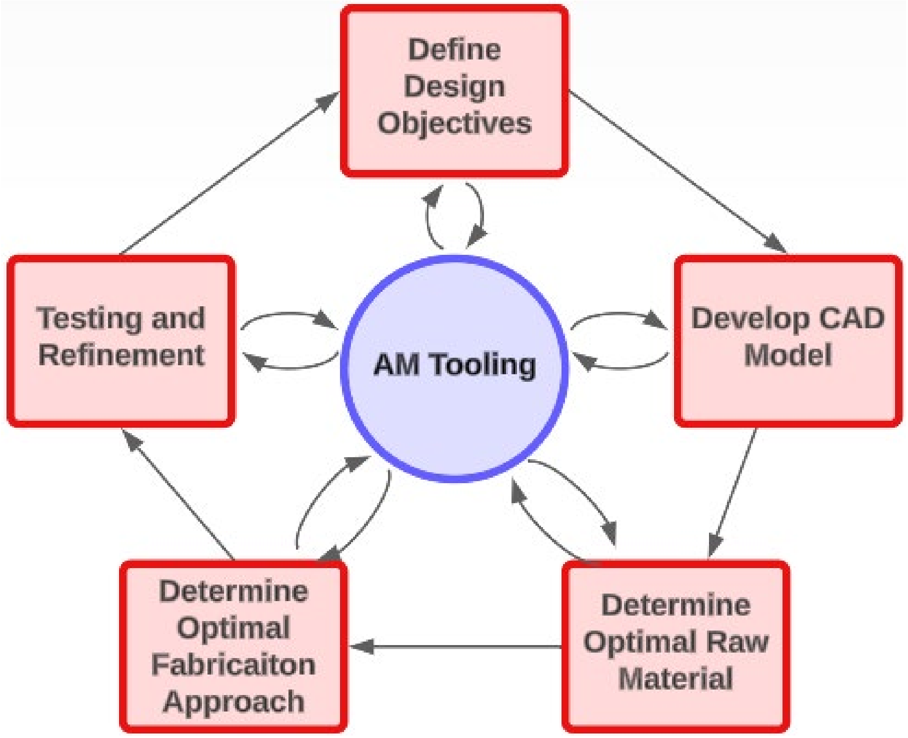
Metal Electroplated AM Tool



Gyroid infill lattice
(Bean et. Al., 2022)

Design for Additive Manufacturing (DfAM) Process

Design for Additive Manufacturing (DfAM): Specifies the process of tailoring the design of a component to be printed to overcome design loads, improve manufacturability, meet geometric constraints, and improve fabrication efficiency.



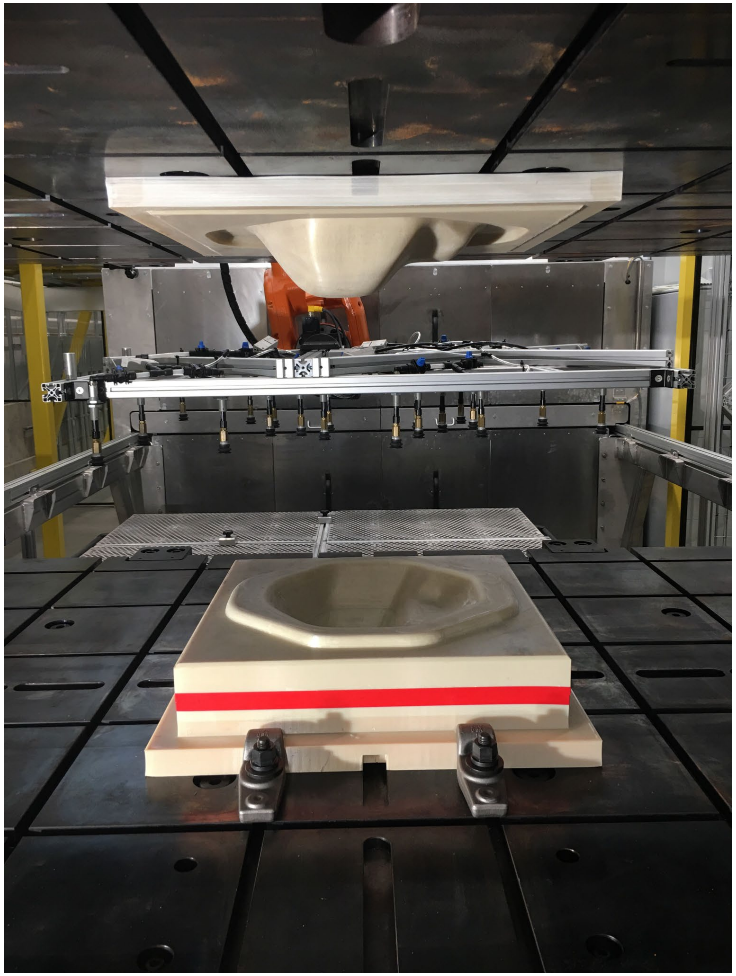
Design for Additive Manufacturing (DfAM) Process

DfAM Process Steps (iterative design process):

1. **Define design objectives:** Thermal and mechanical design load cases, durability and longevity needs, SWaP-C thresholds, and timeline.
2. **Develop CAD model:** Model for loading, geometric printability (self-supporting), reduce mass/cost, avoid monolithic prints, machining and coating offsets, simulate and refine.
3. **Determine optimal raw materials:** Thermal and mechanical performance, reinforcements and additives, feedstock composition (i.e. filament/pellet), printability, machinability, cost, availability, coatings and compatibility, and sustainability.
4. **Determine optimal fabrication approach:** Printer selection, small-scale vs. large-scale, number of components, print orientation, print slicing/topography, supports, embedded components, machining, annealing (if applicable), coatings.
5. **Testing and Refinement:** Prototyping, performance testing, and design refinement.

Small-scale vs. large-scale: Bead size, print environment, cooling rate, deposition rate and costs, reinforcement, filament vs. pellet, high-temperature thermoplastic material limitations.

Case Studies: AM Mold for Differential Cover Fabrication



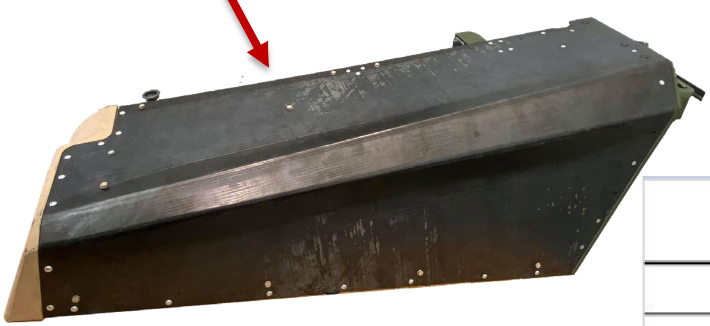
Reengineered steel rear differential cover

- Original steel cover scanned into surface model
- Mold modeled from part scan
- Molds printed using Ultem™ 9085 (~350 °F HDT)
- Preforms heated to about 200 °F using IR heating.
- Preforms shuttled to mold with ABB Robot.
- Parts stamp formed to final net shape at ~100 psi.

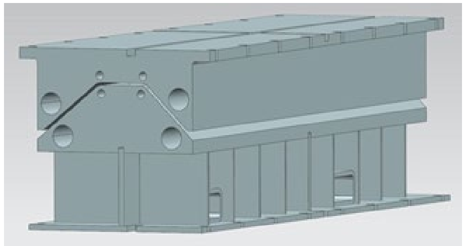
Continuous Reinforced GF/PP | Recycled Discontinuous CF/PP | Recycled Discontinuous GF/PP

Case Studies: US Army GVSC AM Tooling Study

ASCC developed a lightweight thermoplastic HMMWV cargo shell. This initiative also reviewed low-cost tooling for low-volume thermoplastic composite manufacturing. A metallic mold baseline was evaluated against an AM mold.

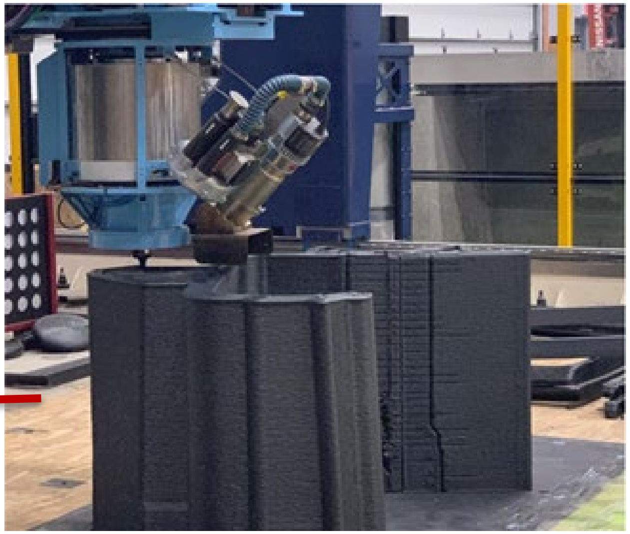


Finished 100% composite part 36% weight savings over original aluminum part.



Conventional Metal Mold

AM Mold with Metal Cladding
60” long x 32” wide x 21” tall



Large Format Additive Manufacturing (LFAM) using ASCC’s Ingersoll Masterprint

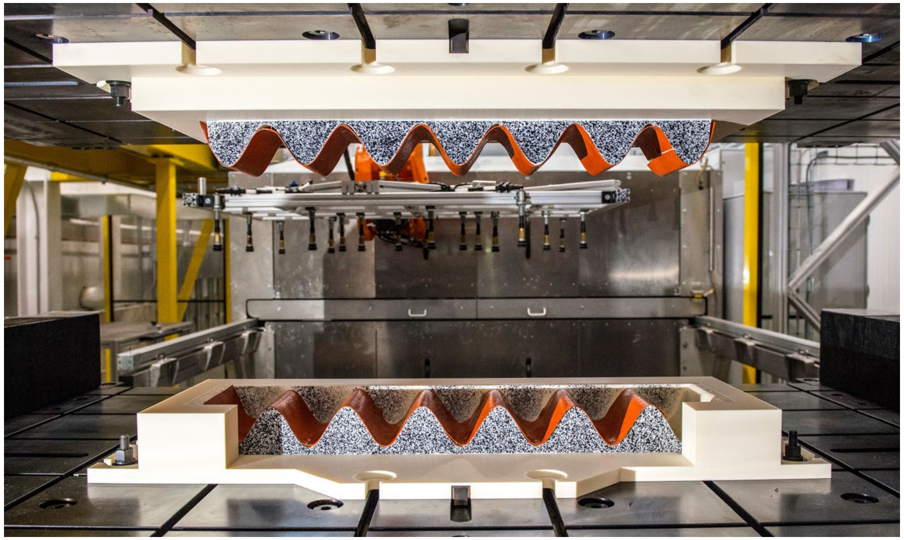
Mold Comparison (Left and Right Side Mold Sets)			
	Cost	Delivery Time	Weight (Mass)
Metallic	$77K	Eight (8) weeks	2,208 lb (1,002 kg)
AM	$50K	Three (3) weeks	1,788 lb (811 kg)

	Cycle Time (hours)	Power/Cycle (kiloWatt)	Energy/Cycle (MegaJoule)
Metallic Mold	2.5	17.1	154
AM Mold	2	4.0	29

(Erb et. al., 2021)

Future Directions in Additive Manufacturing for Tooling

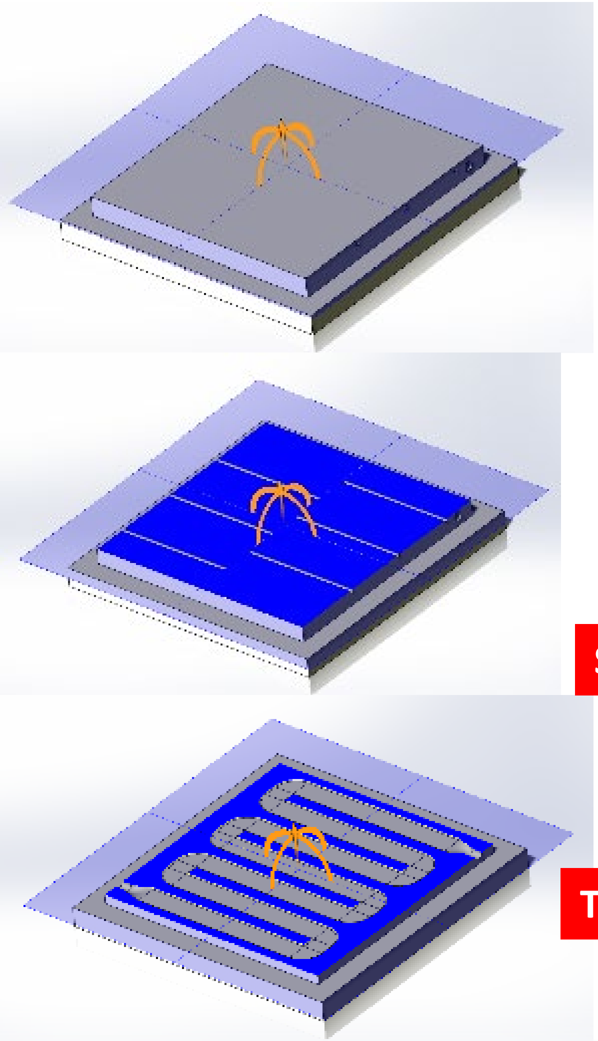
- **Research into new materials:** higher T_g, higher HDT, lower CTE, improved isotropy, bio-based resins and reinforcements, and post-consumer-recycled resins and reinforcements.
- **Hybrid manufacturing methods:** Integrated cooling/heating channels, semi-porous tooling for thermoforming, embedment of fasteners.
- **Smart Tooling:** Integration of sensors such as strain and temperature sensors.
- **Advancements in surface finishing techniques**: Electroplated tooling, porous tooling surfaces.

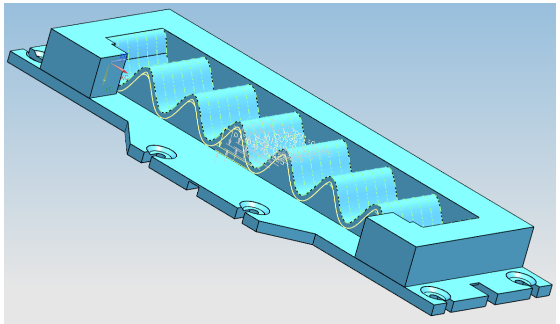


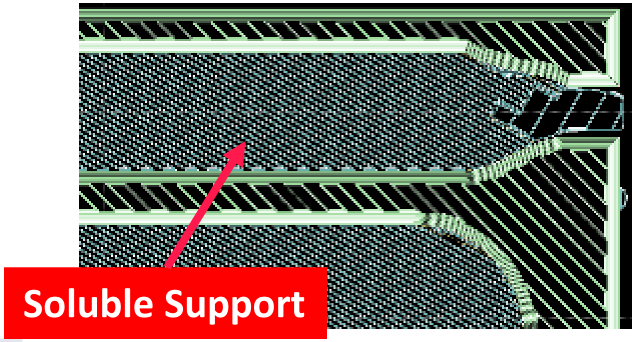
Silicone Tool Surface

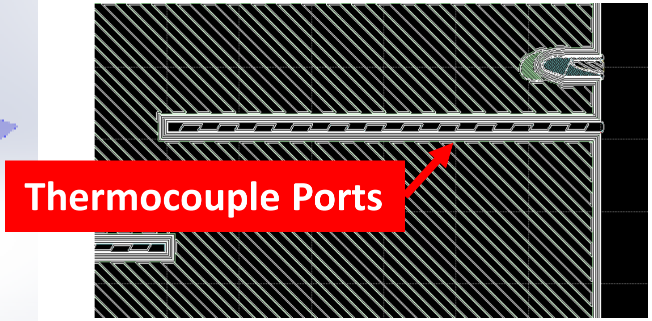
Electroplated PEI Molds

Liquid Cooled Molds









This concept for polycarbonate (PC) mold is cooled with water to form commodity-grade thermoplastic materials.

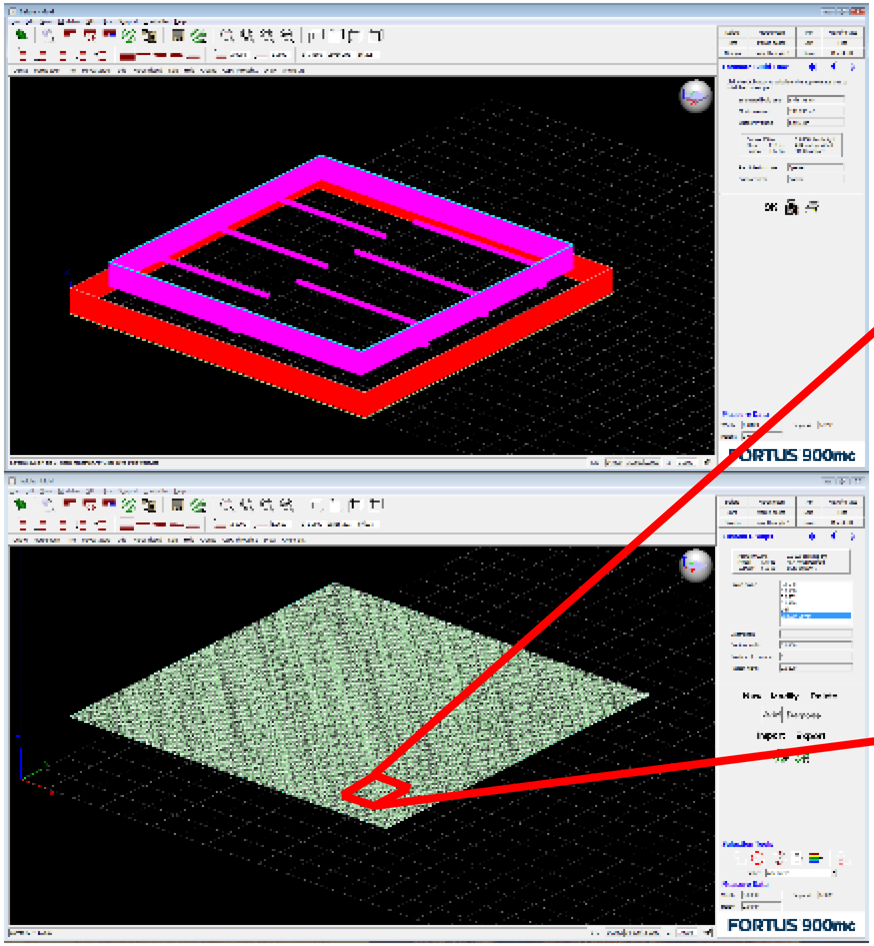
3D Printing Benefit:

- Ability to print tools with internal channels to flush water for mold cooling and temperature maintenance.

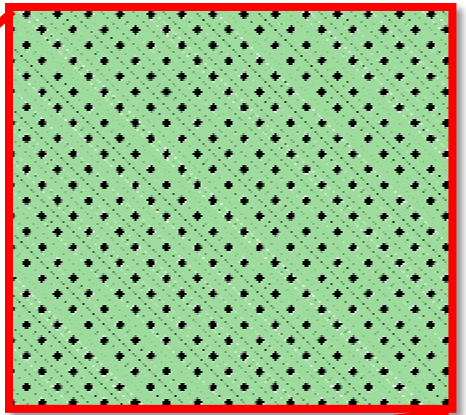
Predicted benefits:

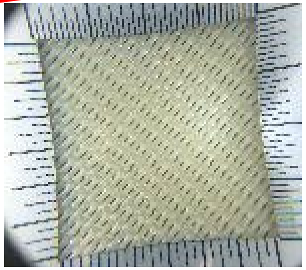
- Increased longevity
- Faster Cycle rates
- Can utilize lower-cost materials for tool printing.

Vacuum / Compression Hybrid Molds



Design for a Ultem™ Vacuum/Compression Hybrid Mold.





3D Printing Benefit:

- Ability to print porous mold surface, which can be used to apply vacuum, positive pressure, or extract water.

Predicted benefits:

- Easier processing
- Cheaper vacuum mold production.
- Can reverse suction to eject parts from mold.

Conclusion and Invitation to Collaborate

Key Benefits to Molded Fiber Products: Rapid tooling production, reduced TTM for manufactured parts, novel and highly customized design approaches catered to the final parts, low-cost low-risk prototyping.

Research Opportunities: Porous thermoforming tooling, tooling prototype development for processing trials, material selections, DfAM support, reengineered tooling (metal to TPC), durability analysis, cycle time studies, technology collaborations, and more.

UMaine is Committed to the Advancement of AM Technologies

If you are interested in collaborating with the UMaine ASCC, please visit the **link below** and click on **Partner with us** to start the discussion.

https://composites.umaine.edu/contact/

Questions?

REFERENCES

1. Bean, P., Lopez-Anido, R. A., & Vel, S. (2022). Numerical Modeling and Experimental Investigation of Effective Elastic Properties of the 3D Printed Gyroid Infill. *Applied Sciences*, *12*(4), 2180. https://doi.org/10.3390/app12042180
2. Erb, D., Dwyer, B., Roy, J., Yori, W., Lopez-anido, R., Smail, A., Hart, R. (2021). Utilizing Additive Manufacturing To Enable Low-cost, Rapid Forming Of High Temperature Lightweight Ground Vehicle Structures [Paper Presentation]. *2021 NDIA Ground Vehicle Systems Engineering And Technology Symposium.* Novi, Michigan. https://tinyurl.com/ycxmwj2r