SKULD

Additive Manufacturing Evaporative Casting

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Team

Sarah Jordan, CEO

B.S Metallurgical Engineering, M.S. Materials Engineering, MBA, PhD candidate Mfg. Eng.
Experience in Marketing, Sales, Forecasting
ISO 9001, AS9100, Nadcap Quality
Certified Lean Champion
America Makes Process & Materials Working Group
5 prior startups

Mark DeBruin, CTO

B.S Metallurgical Engineering, M.A. Applied Mathematics
27 years foundry experience
Started up 5 prior foundries
Certified Lean Six Sigma
SST Vietnam from greenfield to 350 people in 3 months
300+ new designs commercialized

Key Technical Advisors

Dr. Chris Brown, Worcester Polytechnic Institute, Mechanical Engineering

Dr. Alan Luo, Ohio State University, Materials Science & Engineering Dept

Key Commercial Advisors

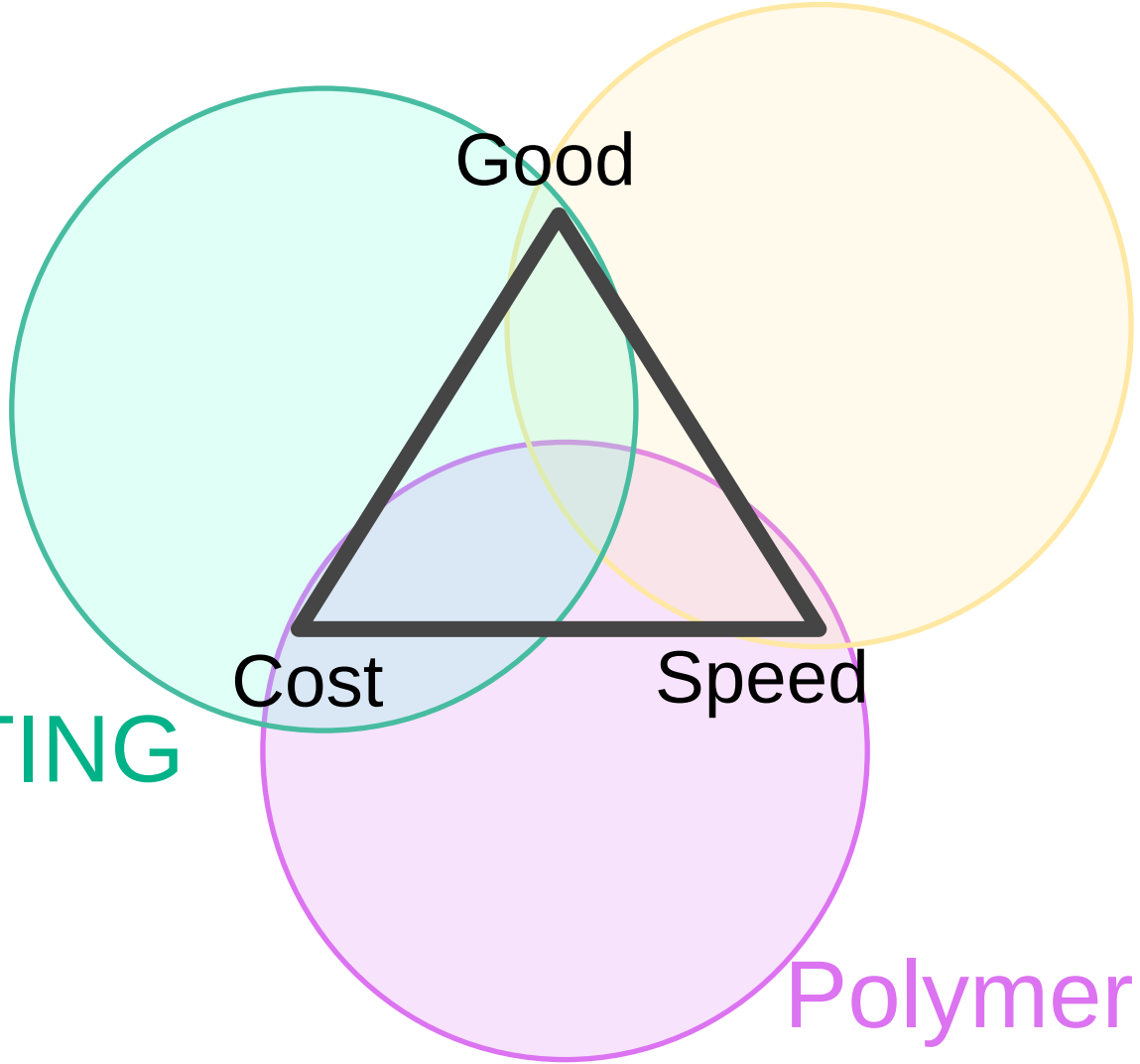
Dr. Emily Ferhman Cory, EIR, Dayton Entrepreneur Center ESP

Peter McDermott, WPI I-corps advisor and IP attorney

Andrea Navratil, Startup advisor, MAGNET: The Manufacturing Advocacy and Growth Network

Jing Lyon, Entrepreneur Programs Director, BRITE Energy Innovators

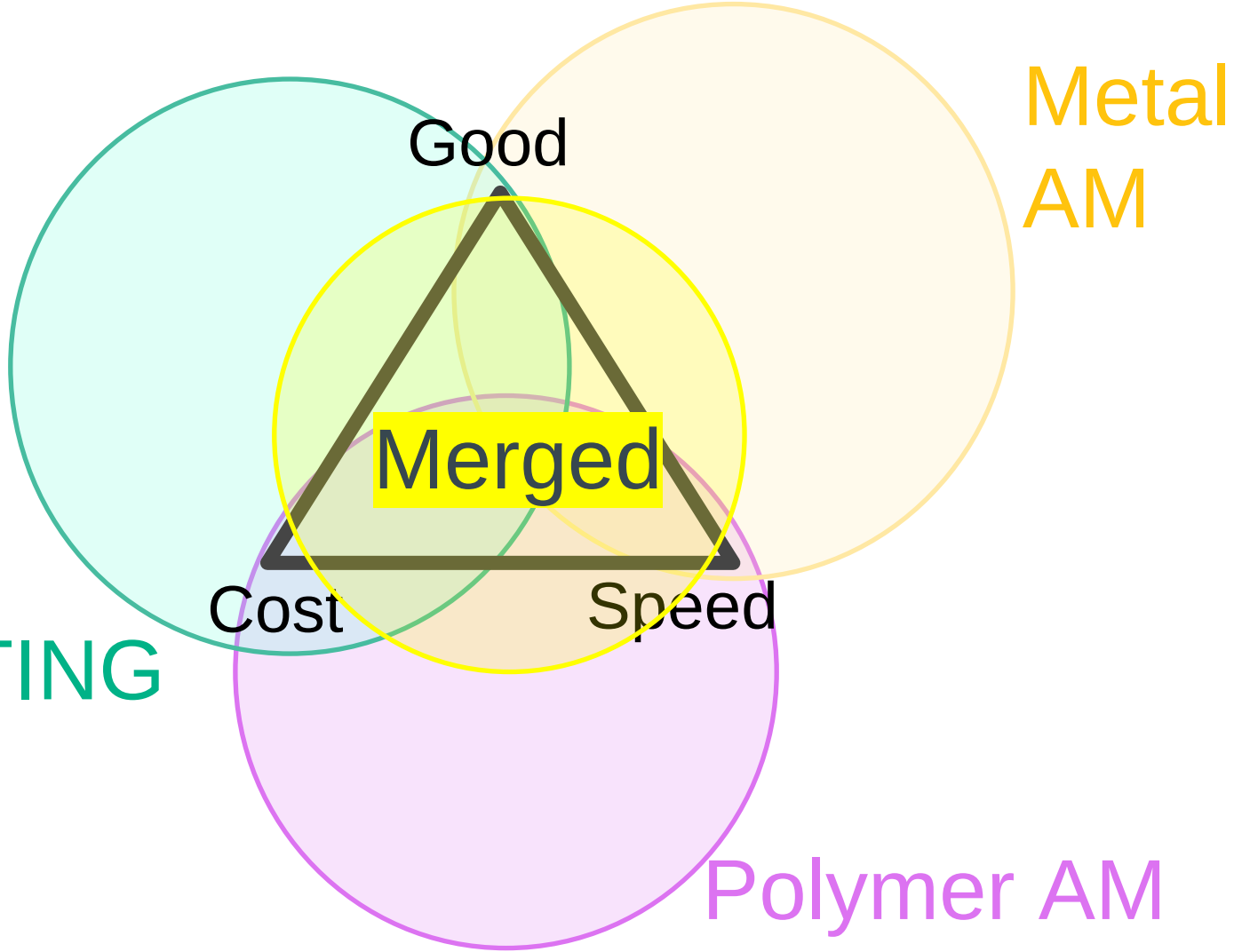
Problem:
IRON TRIANGLE OF MFG



Solution

Merge 3D Printing with Casting in a better way

- Lower cost than traditional casting
- Lower process time by only 3D printing surface
- Merge functionality attributes of parent processes



Additive Manufacturing Evaporative Casting (AMEC)

Polymer 3D Printing

Lost Foam
Investment Casting

Burning a
Biopolymer

Achieve
Replica Part

Rationale

To Use AMEC

Benefits Comparison to Alternatives

No Tooling

10X Better Tolerances Than Sand Casting

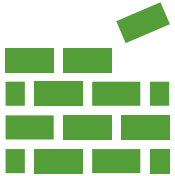
10X Faster Than Lost Wax Casting

10X+ Cheaper Than Direct AM Plus Easier to Qualify

Costs

Raw Material

Scrap + PLA Filament



AM Equipment

$250-$1000 vs.
$250K-$1M+

Post Processing

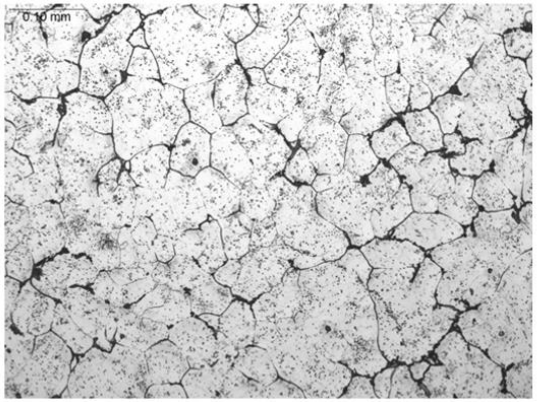
- 0.3% accuracy so minimal machining
- Often no HIP or HT required

Resulting Material is a Casting

Data So Far

- Indicates material is the same as conventional casting

Aluminum 535.0 (aka Almag 35)
Traditional Casting



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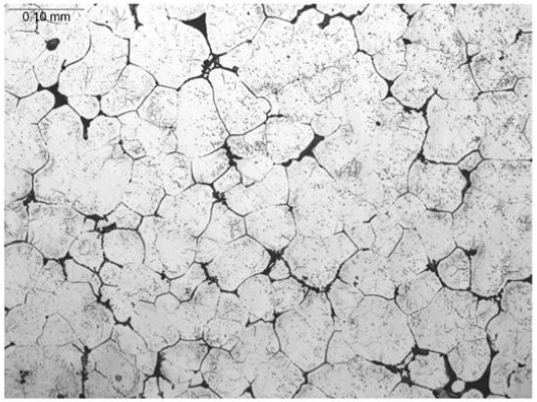
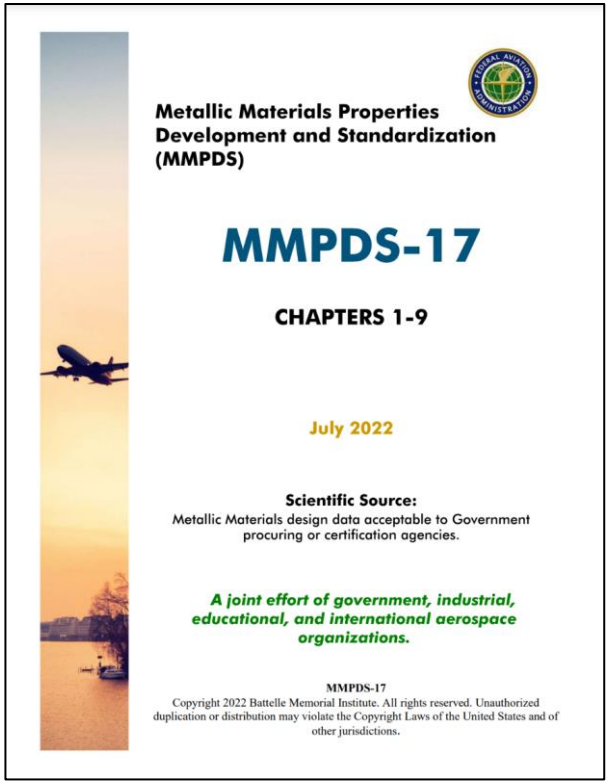
AMEC



Faster & Easier Qualification



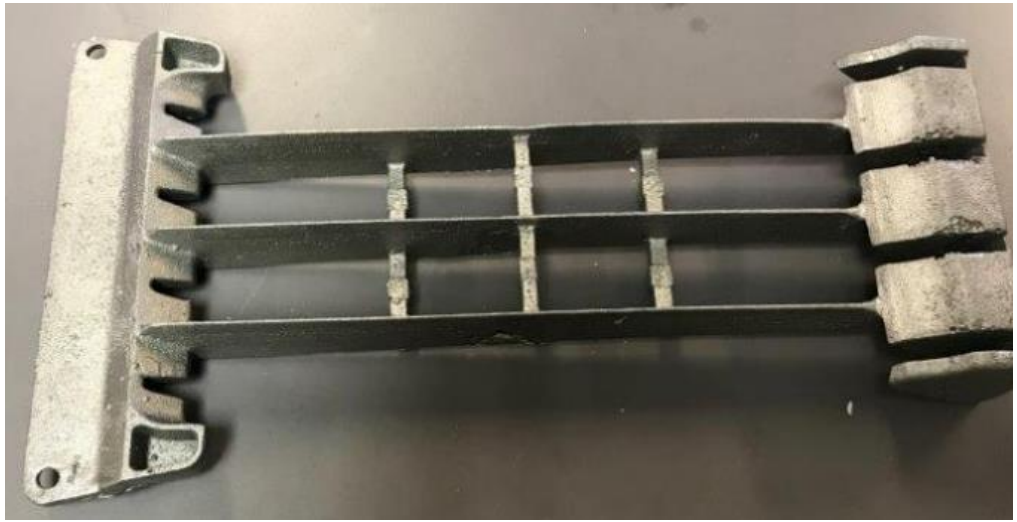
- Direct Metal 3D printing can cost $1M+ per process and alloy to qualify material
- If microstructure the same, implies material is the same.
- If equivalent, can rely on existing material datasets
- For equivalence MMPDS handbook, requires 30 tensile samples from 3 heats, ~$3K

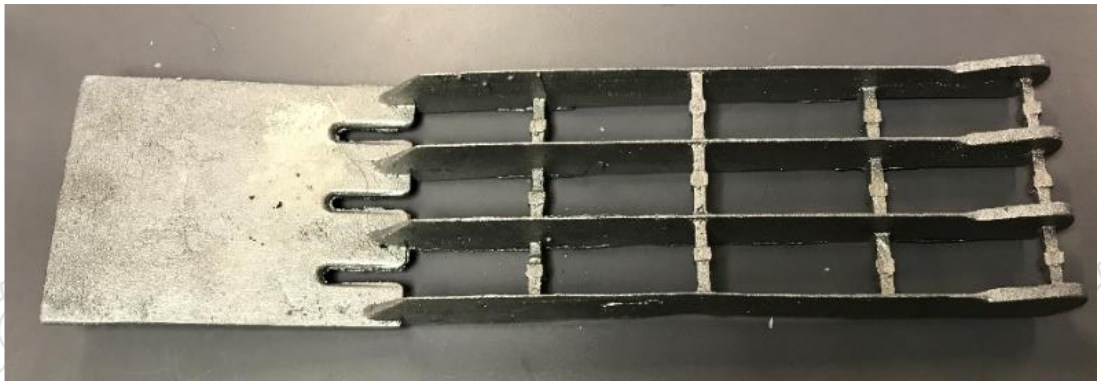
Example Parts

Lost Foam & AMEC

BOAT INDUSTRY PROTOTYPES STOMP GRATE & UNDERPIECE

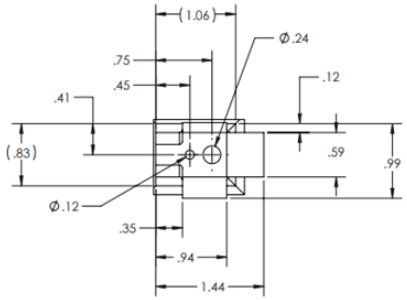
- 12 hours
- Net shape
- Larger piece 85 lbs.
- 1030 steel
- 26 inch long
- Fins 0.125x2x19 inch
- Plate 0.100x7x9 inch

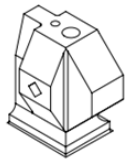


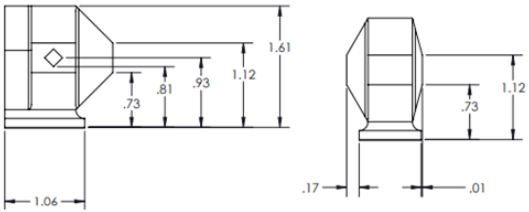


AFRSO Advance Mfg Olympics

- 11 hours
- A535 F
- Cubes - Sharp corners!
- Hexagonal tensiles
- Artifact: Fins 0.5, 1, 2 mm, 0.12 through hole 1.61 deep

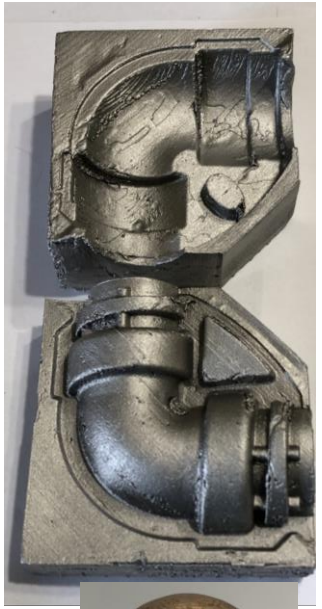




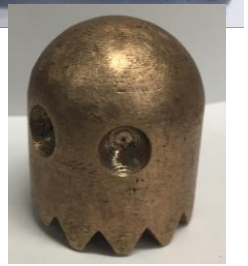


EXAMPLE: America Makes Project to Develop Process with Inconel 713c, 625

- Die for DOM Tube Making of Inconel and Cobalt tubes at Special Metals
- Initial mechanical testing
- OSU R&D Line
- Demo upset die tool




mm/inch
0074
OFF ON ZERO



AMEC Alloy Capabilities

Trials Done

Grey Iron – All Standard Grades
Ductile Iron – All Standard Grades
Steels – 1030, 1040, 1060, 8620, Blak OX
Stainless Steel 304, 316
Aluminum A356, A535 (aka Almag 35)
Brass – C844
CP Copper
Grey Iron – All Standard Grades

Current R&D

Stainless 316L
Inconel 713c, 625, & 718
Overcasting

Customer Inquiries

Monel
Invar
330, 404 Stainless
AF96

Likely Feasible

All cast irons (grey, ductile, white, malleable, CGI)
Most steel alloys
Copper alloys including brass and bronzes
Aluminum cast alloys
Some Nickel cast alloys

Likely Not Feasible

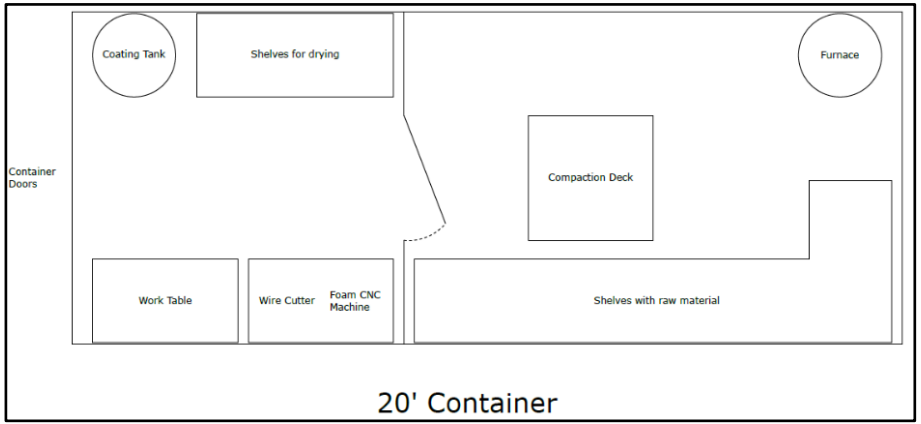
Titanium
Magnesium
Very Low Carbon Steels (<0.015%)*
VIM-VAR Steels*
Alloys that require* melting & casting under a vacuum

*Likely to pick up oxides or carbon

Equipment

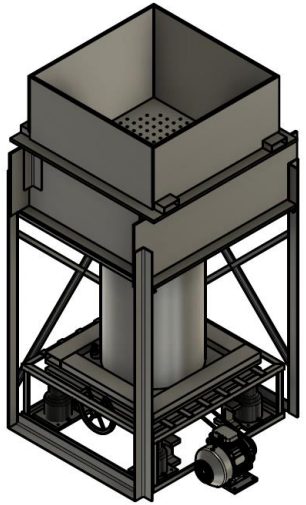
Small Aluminum Machine

Expeditionary Concept



For Existing Foundries

- For AMEC or standard lost foam
- Recently delivered small line to OSU.



For Questions or More Information

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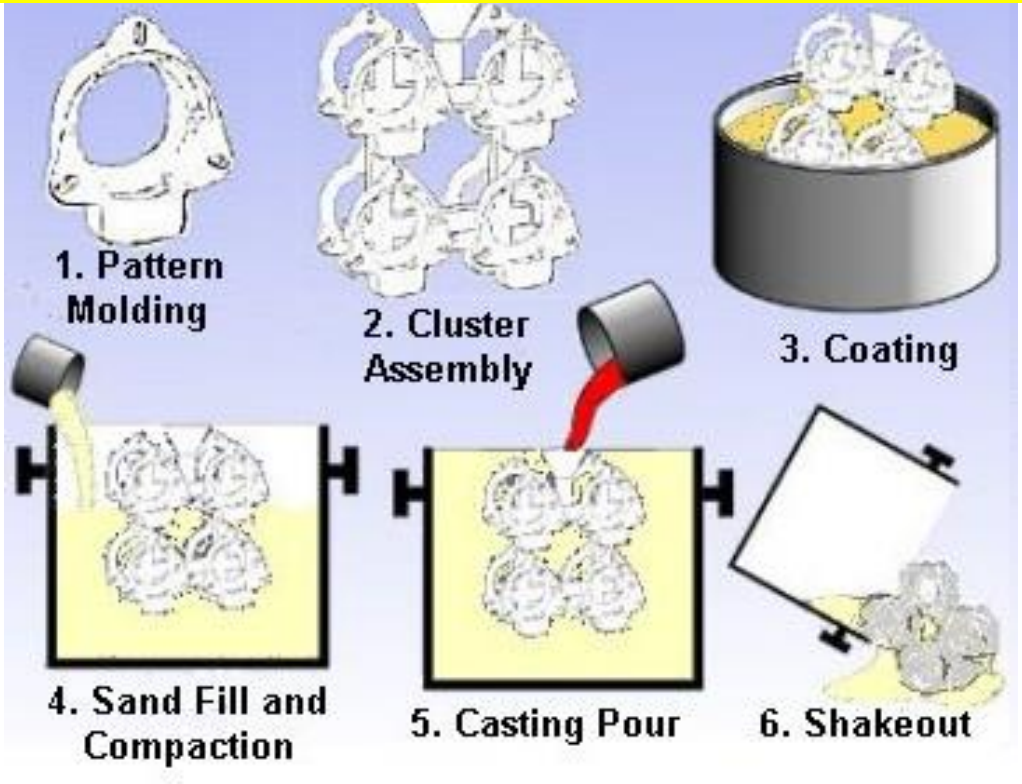
Backup

Additional Information on Lost Foam Capabilities

Background: Lost foam Casting

Key Point: Invented to reduce lost wax investment casting process time from 3 weeks to less than 1 day.



Example Lost Foam Castings

Key Point: As good as 0.2% tolerances minimizes/eliminates metal machining

With Tooling

Machined Foams (small volumes)

Lost foam Can make “Impossible shapes”

- Done by joining 1 or more foams
- Internal channels
- Blind Holes
- Complex Shapes
- Alternating or no draft
- Interlocking Shapes
- Threads

Deeper Dive – Mcdonald Steel Rapid Replacement Gear

- Steel rolling mill built in 1926 (US Steel)
- Main drive gear failed in 2009, entire plant down
- No Spare
- No CAD (actual paper prints)
- Gear 24” diameter, 4 inch thick
- 120 lbs., 1060 steel
- Lead time to obtain steel and machine it: 12 weeks
- Reverse Engineered and Delivered: 4 days
- Net/near net shape: Gear teeth accurate as cast, ground bore slightly
- Still in use

Standard Lost FOAM CASTING Design Capabilities

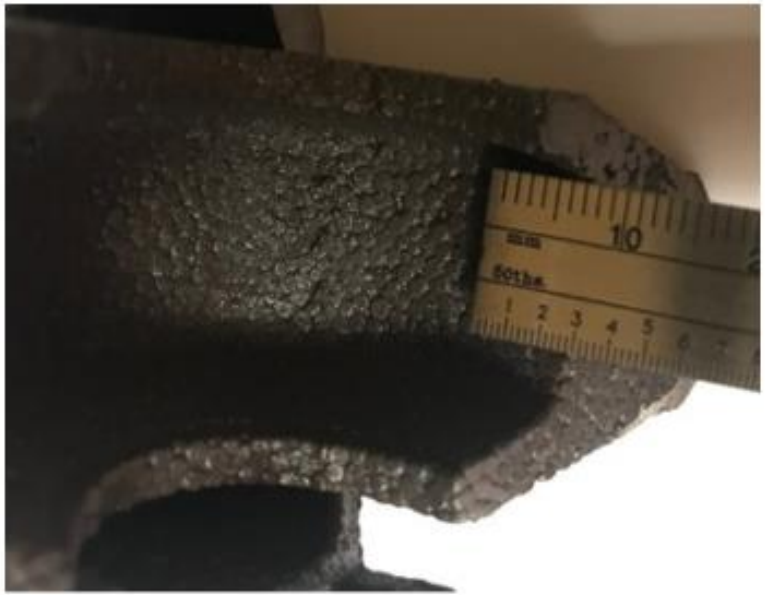
- Good for high or low volume parts, prototypes, sustainment, or tooling
- Highly complex geometry
- Size Range
  - Fins as thin as 0.040”
  - Size limited by melt furnace (~650 pounds currently)
  - Lost foam known up to 25 ton parts

Example : 304 SS Bolt Cover

Part is 0.100” thick and weighs 2.5 pounds

Lost Foam Materials POSSIBLE

- Aluminum
- Gray iron
- Ductile iron
- Brass
- Copper
- Steels including low* and medium* carbon steel and stainless
- Thin walled ductile iron* down to 0.030 inch (DOE SBIR)



Sample thin walled ductile iron lost foam casting going to 1.5mm (0.060") in places.

*Unique to Skuld in lost foam

Novel Material: CoEDI
Designed for “unbreakable Gear Teeth”

- Carbidic Outer Edge Ductile Iron (COEDI)
- John Deere requested unbreakable gear teeth but when life tested they jammed teeth with rebar resulting in shaft breaking which required system redesign.
- Made by Surface Alloying on lost foam with carbide formers to create iron carbide at selected locations on the surface of ductile iron
- Surface 75+HRC without heat treating and stable to 1400F.
- Ductile interior up to 12%
- Patented, **US20100296961A1**
- For uses needing high strength, wear, abrasion/impact resistance