BINDER JET TOOLING FOR COMPOSITES

Team ExOne

Oct. 27, 2021

Today's Agenda

Exploring an innovative, sustainable new tooling method

1. **Composite Tooling Options**
2. **Why Binder Jet?**
3. **X1 Layup**
4. **X1 Washout**
5. **Q&A**

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ExOne | The Benefits of Using Our Technology

Infiltrated sand 3D printed tooling helps manufacturers solve supply chain issues

3D SAND MOLDS AND CORES FOR METALCASTING

Complex molds and cores in days instead of weeks and months. Pattern-less production for sandcasting.

DIRECT METAL 3D PRINTING

Custom or mass production of complex single-alloy metal parts in hours versus weeks or months.

DIRECT CERAMIC 3D PRINTING

3D printing greatly simplifies production of difficult to produce ceramic materials, such as silicon carbide.

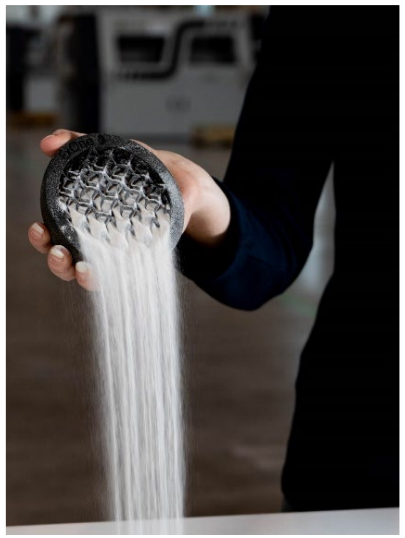
INNOVATIVE 3D PRINTED TOOLING SOLUTIONS

Affordable, time-saving 3D printed tooling solutions for complex sacrificial, vacuum- and hydro-forming.

Binder Jetting | Overview

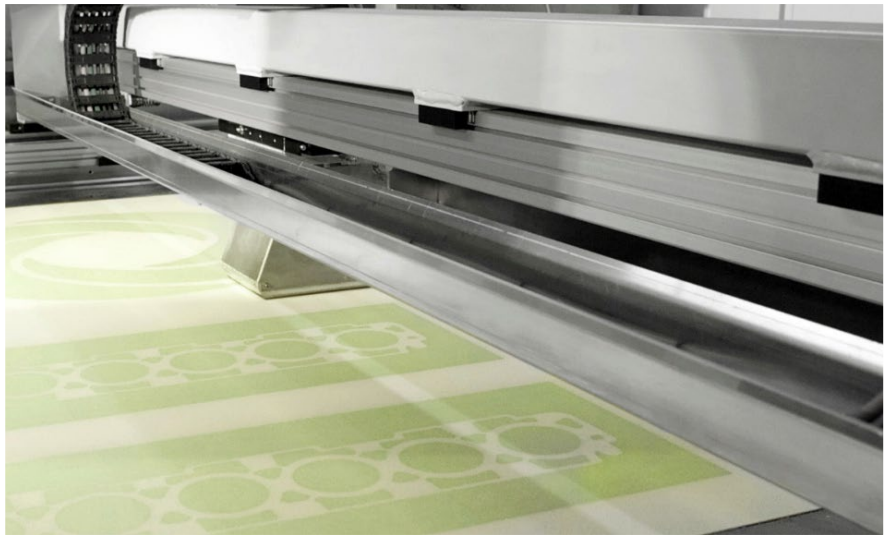
Patented in 1993 by Massachusetts Institute of Technology

POWDER → **BINDER** → **PRINT EACH LAYER**



Sand, Metal, Ceramics, Composites

Liquid binder adheres powder and layers together

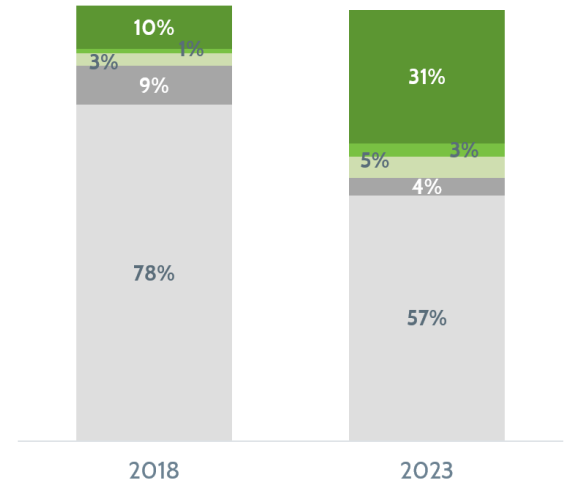


- Layer of powder is spread into the print bed
- Industrial printhead lays down binder fast sweeps.
- Recoater dries layer and lays down fresh powder
- Process is repeated until the part is complete and ready for post-processing.

CORE BENEFITS

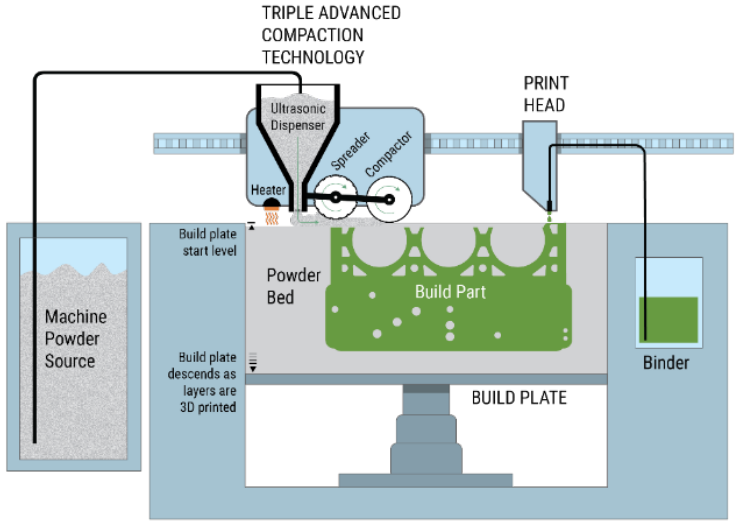
- High processing speeds
- Scalable, large systems
- Small or large parts
- Many materials
- Low operating cost
- Easy to operate

AM Power Forecast



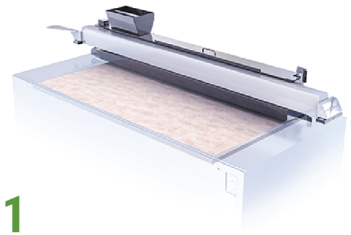
Binder Jetting | Process Overview

Liquid binder applied to powder to form parts and tooling

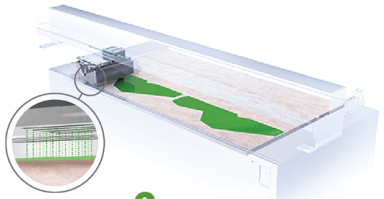


Digital File Prep → Machine & Material Prep

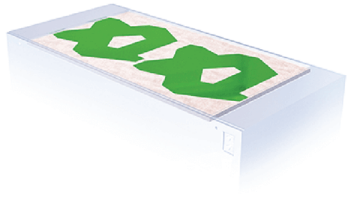
3D Printing



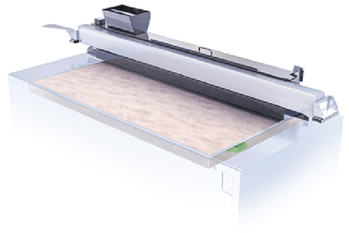
1 Powder is deposited.



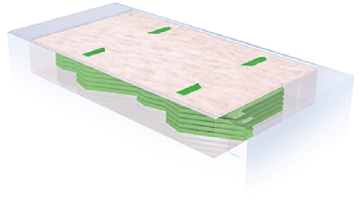
2 Inkjet applies binder.



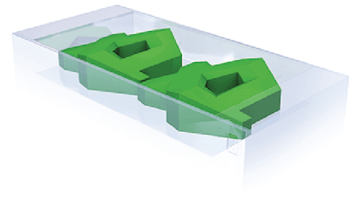
3 Each layer is printed fast.



4 Powder is recoated.



5 The process repeats.



6 3D printing is complete.

Next steps depend on application and specific materials →

- Sand molds & cores → Depowder → Cure optional
- NEW Sand tooling → Depowder → Coat or Infiltrate
- Metal and ceramics → Cure → Depowder → Debind & Sinter

ITERATIVE PROCESS WITH BIG PAYOFFS

The Core Benefits of X1 Layup

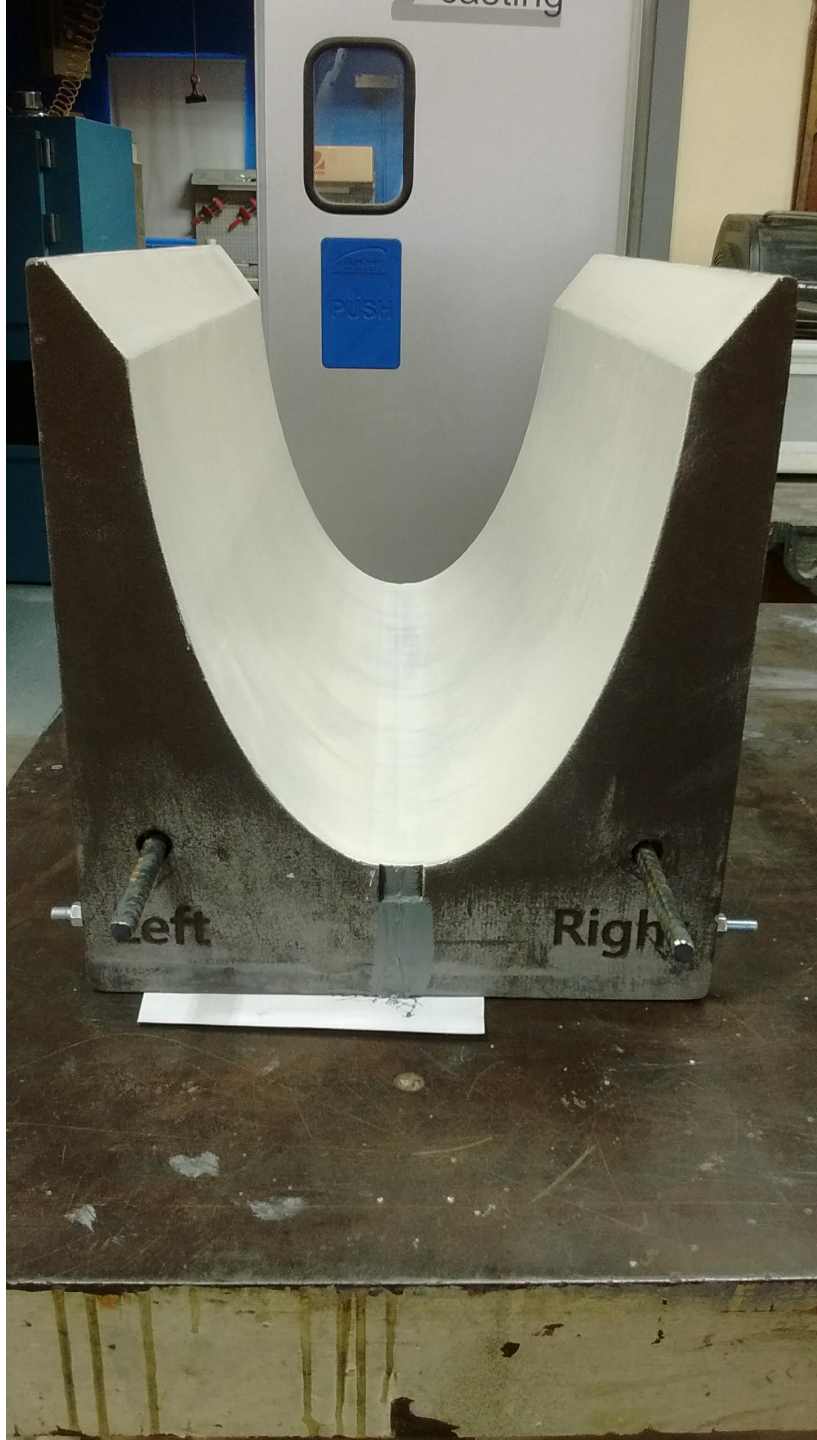
Innovation acquired through acquisition of Freshmade 3D

FAST
Eliminates long lead times needed for traditional tooling. Durable tools at reduced costs.

EASY
Domestic U.S. production without international shipping logistics and delays.

PRECISE
Expansion of the tool is completely isotropic and controlled by the print media. Low or high CTE available.

FLEXIBLE
Design flexibility to create unique geometries and integrate value-add features such as vents or cooling channels.



The Core Benefits of X1 Washout

A fast, easy-to-use, affordable form of sacrificial tooling

FAST

Eliminates long lead times needed for most other forms of sacrificial tooling. Quick removal of tool.

EASY

Washes out with tap water. No need for hot solvents, detergents, deflatable tools and complex tool removal.

PRECISE

Expansion of the tool is completely isotropic and controlled by the print media. Low or high CTE available.

SUSTAINABLE

The sand or ceramic sand media used in the process is reusable, making this tooling process sustainable.

Today's Presenters

Rich Wetzel

- Applications Manager
- X1 Layup

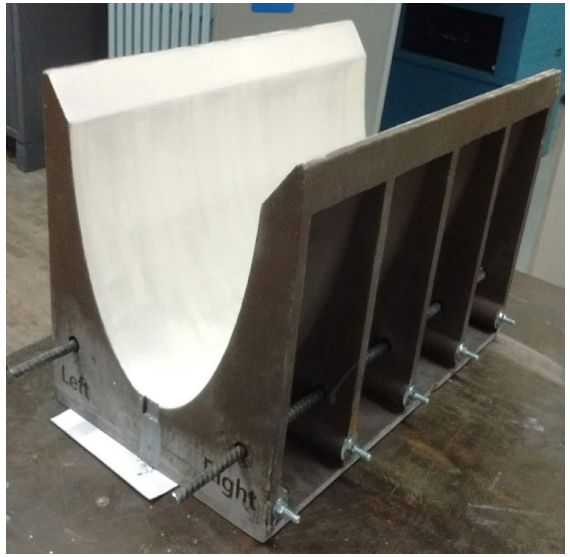
Brad Stocking

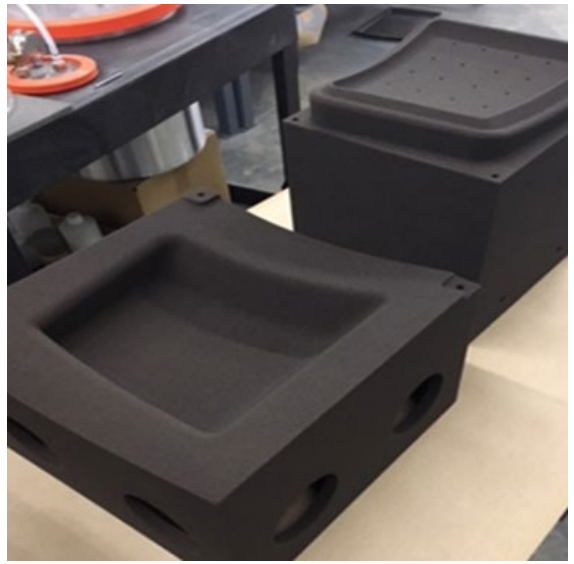
- Technical Applications Manager, New Markets
- X1 Washout

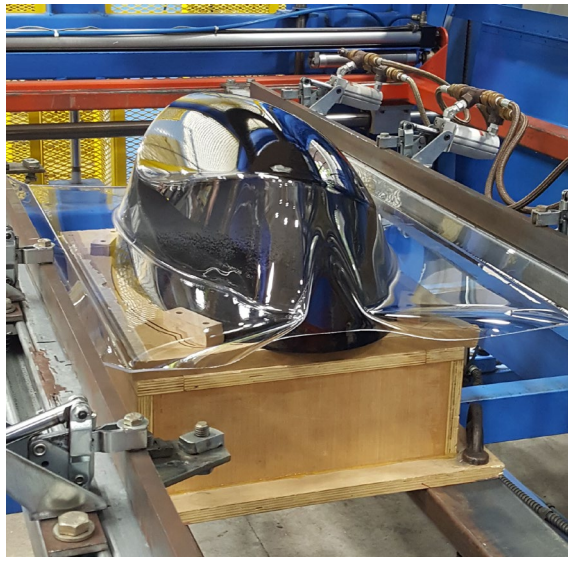
INTRODUCING
X1 LAYUP TOOLING

ExOne Acquires Assets of Freshmade 3D

As the pioneer in binder jet 3D printing technology, ExOne recognized the potential of the infiltrated sand process patented by Freshmade 3D. With ExOne sand binder jetting machines at its core, the process takes advantage of the fast output and large-scale capabilities of the S-Max family of machines to quickly create complex shapes without hard tooling that are transformed into durable, functional parts used as tooling for a variety of forming applications as well as architectural restorations.



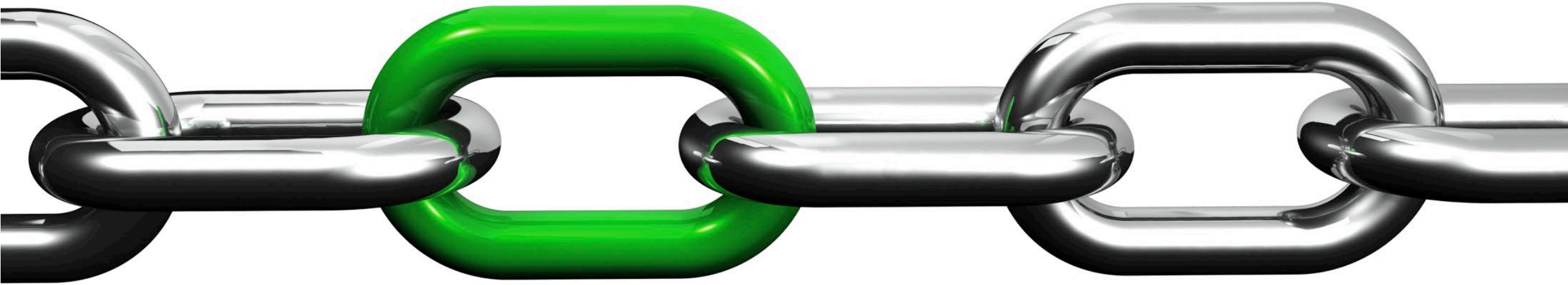




X1 Layup | Local Tooling Supply Chain Solution

Infiltrated sand 3D printed tooling helps manufacturers solve supply chain issues

- Get to market faster
  - Digital manufacturing workflow of 3D printing enables rapid turnarounds
  - Produced in the United States without the uncertainty of international shipping logistics
- Cost-effective, streamlined operations
  - Reduce costs 40% to start immediate production or test functional prototypes with the fast iterations of rapid tooling
  - Sustainable tooling produced without the waste of milling swarf



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X1 Layup | Where Does Infiltrated 3D Sand Fit?

Parameters to consider for composite layup tooling

1

Temperature

- Tool coatings design to withstand the temperatures and pressures of autoclave or vacuum bagging
- Service temperatures vary by coating, but typically allow for operation up to 350°F
- Development partnerships to tailor coatings to specific customer application requirements

2

Precision

- Tolerances of +/- 0.030”
- Tools can be machined to achieve tighter tolerances when necessary
- CTE value (12 ppm/°F) comparable to aluminum and stainless steel

3

Durability

- Designed to withstand the temperatures and pressures associated with the production of industrial composites over multiple cycles
- Good success on development projects and results from high-temperature, high-pressure thermoforming customers provide confidence

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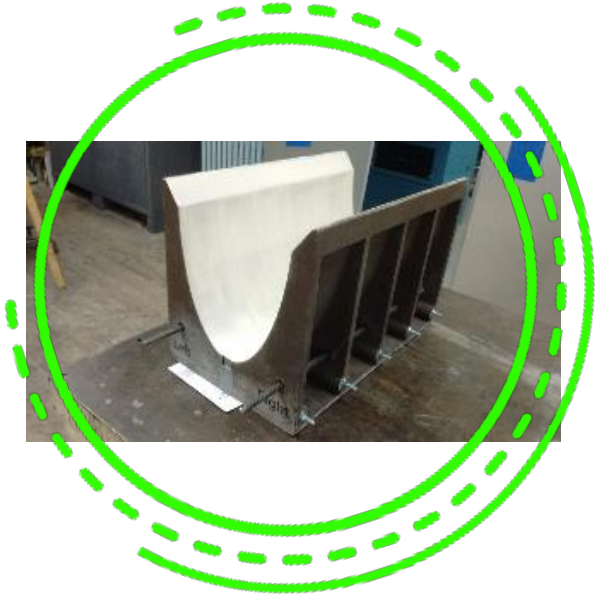
X1 Tooling Application Example | Composite Layup Tool

Reduced turnaround tooling times with comparable CTE performance

INDUSTRY Tooling & Fixtures
APPLICATION Leading edge airfoil composite layup tool
LOCATION Dayton, Ohio
CHALLENGE Project to identify an alternative process or material with comparable properties to existing composite layup tooling solutions. Multiple processes and materials were tested by the University of Dayton Research Institute and Youngstown State University.

SOLUTION
3D PRINTING ExOne S-Max®
MATERIAL Silica sand infiltrated with epoxy and coated for composite
BENEFITS The composite layup tool demonstrated a CTE of 19.67 µm/m°C; a performance better than aluminum (~23µm/m°C) and comparable to stainless steel (~18 µm/m°C). Sub-scale testing successfully demonstrated 10 cycles of 350°F and 100psi in autoclave before a full-size large-scale tool was printed in two halves, bonded together, and delivered in a few weeks.



After successful sub-scale testing, a final tool could be completed and delivered to the University of Dayton Research Institute for autoclave layup in under three weeks

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X1 Tooling Application Example | Composite Layup Tool

Cost-effective tooling produced domestically with short lead times

INDUSTRY Aerospace
APPLICATION Publicly shareable composite layup tool
CHALLENGE This composite layup mold was designed to mimic common features we've seen on projects and to demonstrate some of the unique features available with X1 Layup tooling

SOLUTION
3D PRINTING ExOne S-Max®
MATERIAL Silica sand infiltrated with epoxy and coated with a durable vinyl ester for composite layup
BENEFITS Multiple estimates for machining the tool in aluminum ranged averaged $11,000 with a three-week lead time. The X1 Layup tool with a profile tolerance of 60 was produced in two weeks for only $6,000.

X1 Layup 3D printed infiltrated sand reduced tooling lead time by a third and was 45% cheaper than traditional machined aluminum

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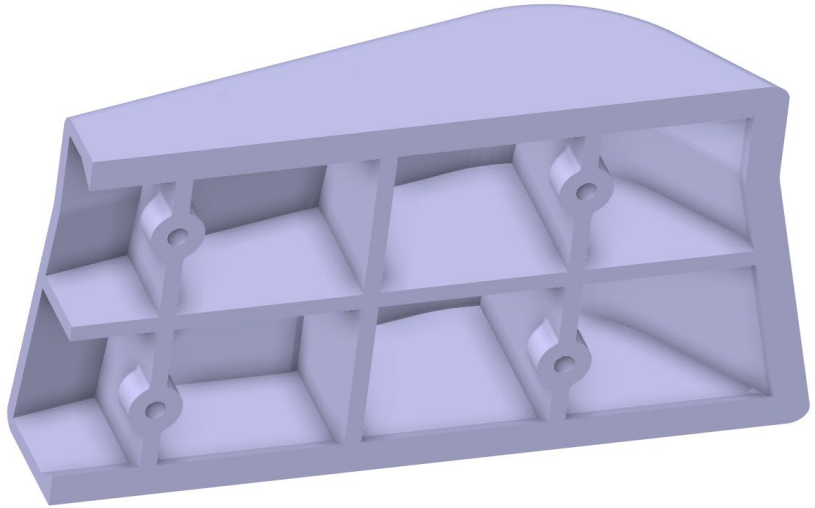
X1 Layup | Tool Design Guidelines

Considerations and workflow for optimized 3D printed tooling

Design for Additive Manufacturing → **Optimization for Binder Jetting** → **Optional Value-Added Features**

- Start with a clear understanding of the requirements of the part itself
- Design for Additive Manufacturing (DfAM)
  - Reduce weight
  - Reduce cost
  - Reduce thermal load
  - Reduce assemblies with consolidated geometries



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X1 Layup | Tool Design Guidelines

Considerations and workflow for optimized 3D printed tooling

- Increased benefits with Binder Jetting
  - No supports needed on overhangs
  - True production speeds
  - Large format printers and ability to print multiple sections with designed connections for even larger tools
- Design lattice structural reinforcement for critical areas
  - Level of support varies based on application
  - Adequate spacing is needed to accommodate for the infiltration process
  - Wall thickness of 0.5" recommended for most applications, speeds up processing

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X1 Layup | Tool Design Guidelines

Considerations and workflow for optimized 3D printed tooling

- Integrate mounting features
  - Design cart or press mounting features
  - Add bosses to connection points and pilot holes for inserts
  - Add lifting holes for tool and support manipulation
    - Important for extracting large parts from the S-Max
- Add venting or cooling channels for faster cycle times
  - Vent for heated airflow where required
  - Add thermocouple well for crush core and compression tooling

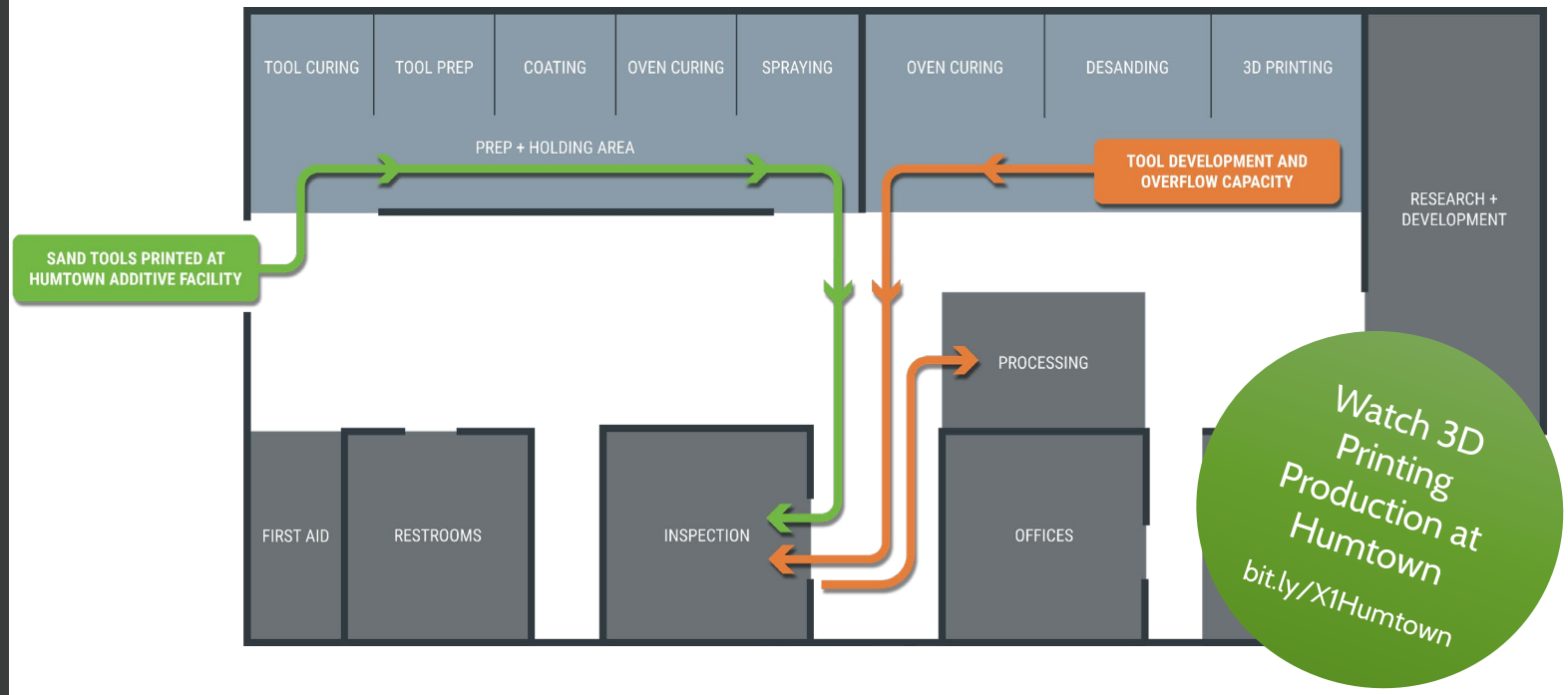
ExOne

X1 Layup | The Future of Tooling

Capacity to scale with a roadmap to offer development and rapid production tools

We're working on the future of tooling while already supplying OEMs and innovative companies with infiltrated sand tooling today.

- Domestic production in Leetonia, Ohio
  - Co-located with Humtown Additive, operators of the largest collection of sand 3D printers in the country
  - All tools inspected in-house before shipping
- Facility expansion mapped for development projects and production expansion
  - Roadmap to optimize for future tool delivery in 1.5 weeks or faster



Co-located partnership with production capacity on fleet of ExOne sand 3D printers

X1 Layup | Frequently Asked Questions

What if my application requires temperatures over 350°F?

Most applications work within that range, so it's our standard offering. Partnerships with customers to tailor process to advanced requirements at higher temperatures.

How can I print even larger tools?

Design freedom of binder jet enables nesting of multiple segments that are bonded together before infiltration to produce precision tools larger than one build box

What is the lifespan of a tool?

It depends on the specific application. Performance data collected from X1 ThermoForm tooling indicates industrial durability through 200+ cycles

Are tools repairable?

This also depends. Yes, the topcoat can be touched up and filled in the case of damage

INTRODUCING X1 WASHOUT TOOLING

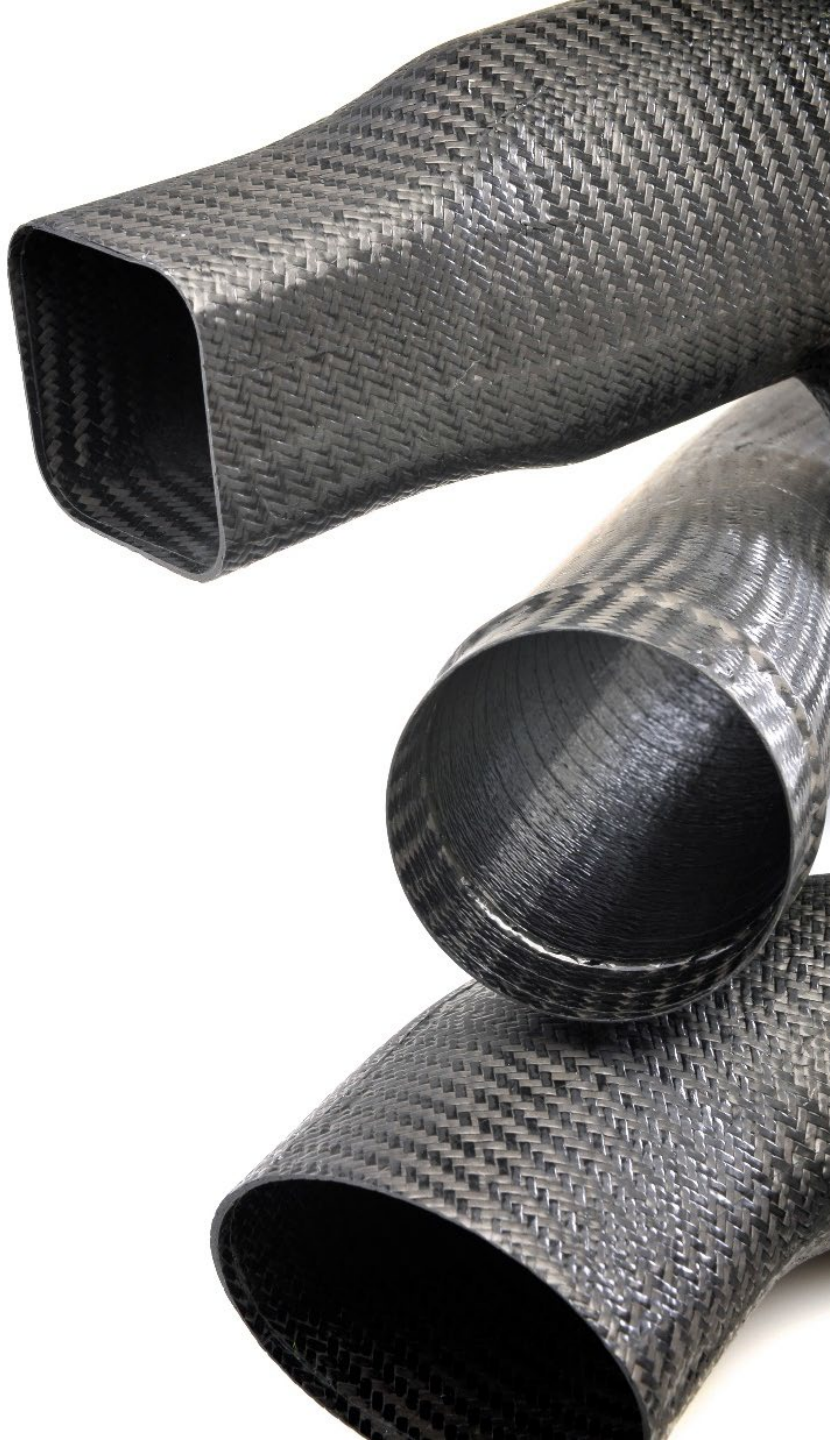
What is Washout Tooling?

A new form of 3D printed sacrificial tooling

A new and sustainable method of creating lightweight parts with trapped geometries, such as ducting, tanks, struts, mandrels, and rocket shrouds.

With this ExOne-exclusive form of sacrificial tooling, a tool is 3D printed in sand or ceramic sand and then coated with a proprietary spray or a Teflon tape so that it can be used for layup of carbon- or glass-fiber thermoset composites.

After autoclaving, the tool can simply be washed out with tap water. This is possible because the binder used in the 3D printing process remains water soluble up to 180° Celsius or 356° Fahrenheit throughout the process.



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The Core Benefits of Washout Tooling

A fast, easy-to-use, affordable form of sacrificial tooling

FAST

Eliminates long lead times needed for most other forms of sacrificial tooling. Quick removal of tool.

EASY

Washes out with tap water. No need for hot solvents, detergents, deflatable tools, and complex tool removal.

PRECISE

Expansion of the tool is completely isotropic and controlled by the print media. Low or high CTE available.

SUSTAINABLE

The sand or ceramic sand media used in the process is reusable, making this tooling process sustainable.

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Washout Tooling | Customers

Choose a low or high CTE to manage expansion

Aerospace & Defense

We serve a wide range of customers in this market, including makers of UAVs, with tooling for parts.

- Ducting
- Shrouds for missiles, rockets, engines
- Structural composites (Stiffeners, fly-away foam replacement, etc.)
- Pressure tanks

Automotive

We serve the NASCAR, Performance and Luxury automotive markets with tooling for a variety of parts.

- Ducting
- Tanks
- Structural composites

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Washout Tooling | Customers

Aerospace customers benefiting from the technology

Sikorsky CH-53K King Stallion

Air ducting being fabricated for production units of this heavy-lift cargo helicopter

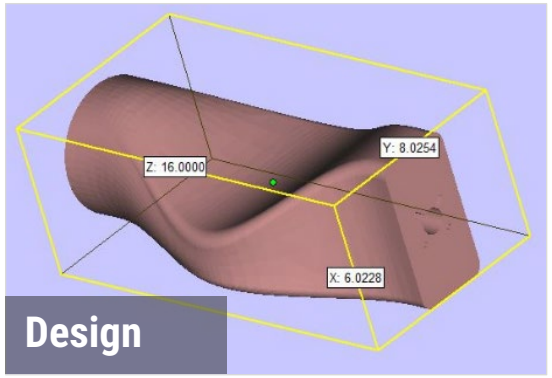
- Now in Logistics Demonstration (LOG demo)
- The Marines intend to purchase a total of 200 CH-53K helicopters, the successor to the CH-53E Super Stallion

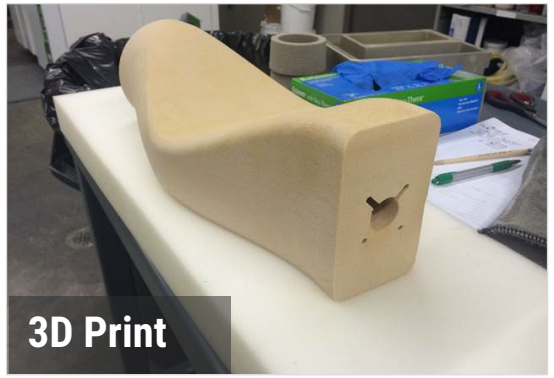
Washout Tooling | Process Overview

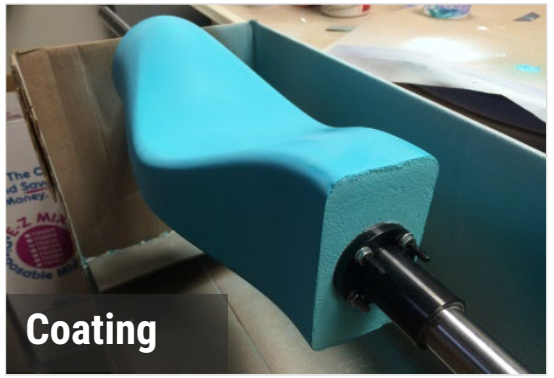
Design › 3D Print › Coating › Layup › Autoclave …

Processes supported by washout tooling include:

- Hand/wet layup
- Pre-preg layup
- Filament winding
- Tape or fiber placement







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Washout Tooling | Process Overview

Simple Water Washout › Final Part

Remove Tool with Tap Water

Recover and Reuse Sand Media

Final Fiberglass Part

Washout Tooling | Print Media

Choose a low or high CTE to manage expansion

ExOne binder jet machines 3D print traditional sand and ceramic sand media into a tool with a binder that remains water soluble up to 180° Celsius or 356° Fahrenheit throughout the process. Expansion is driven by the media, not the binder, and it's isotropic (XYZ), resulting in high-quality results.

Silica Sand
CTE
20 ppm/°C
(11 ppm/°F)

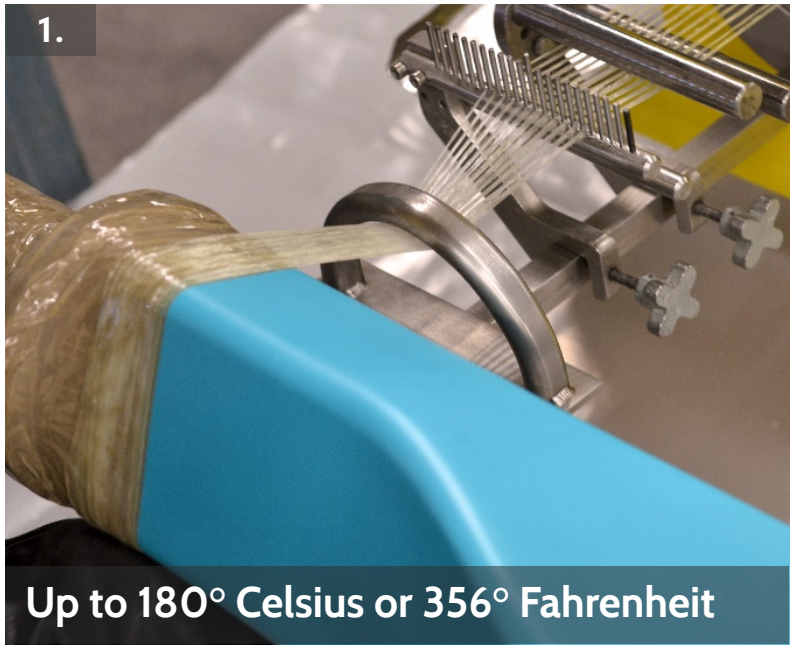
Ceramic Sand
CTE
3 ppm/°C
(2 ppm/°F)

3D Printed Form
Before Coating

Washout Tooling | Coating Options

Prevent resin migration into the porous 3D printed tool form

ExOne offers two forms of proprietary spray coatings for its 3D printed tooling, in addition to Teflon tape wrapping. The blue coating remains water soluble up to 180° Celsius or 356° Fahrenheit while the green coating remains water soluble up to 132° Celsius or 270° Fahrenheit.



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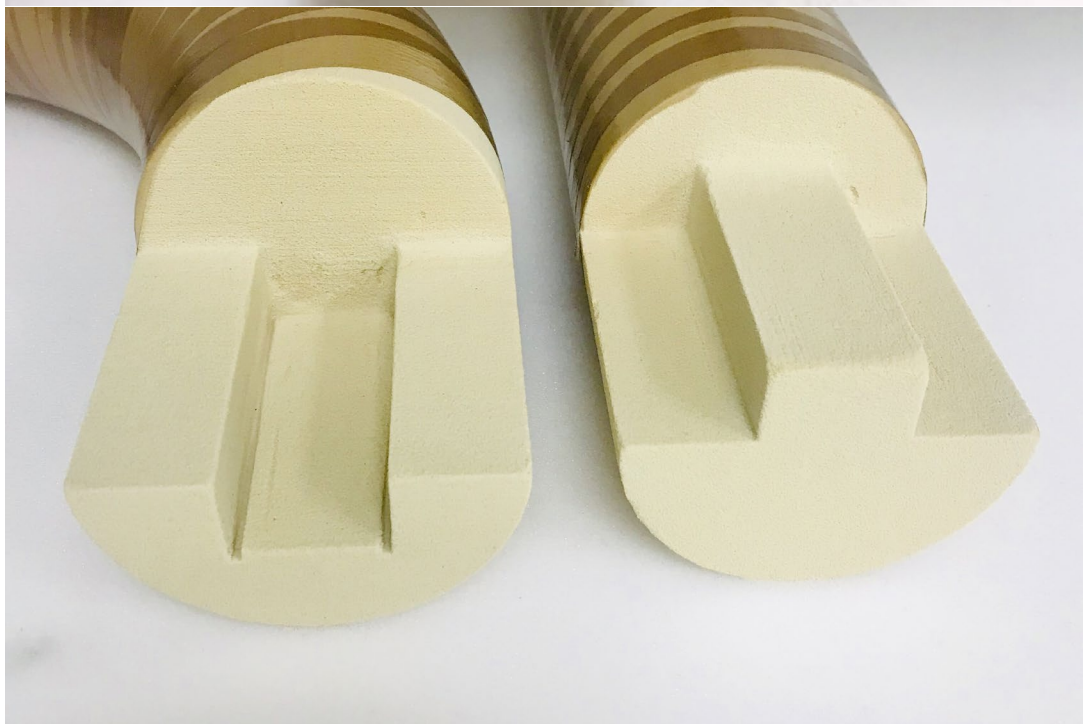
Extreme Design Benefits

Choose a low or high CTE to manage expansion

- Novel designs printed in ends of mandrels to create longer mandrels
- Creates ability to manufacturer parts longer than the build volume (L > 800mm)
- Minimizes shipping issues and potential damage to shipping long mandrels
- A lot of unexplored design possibilities



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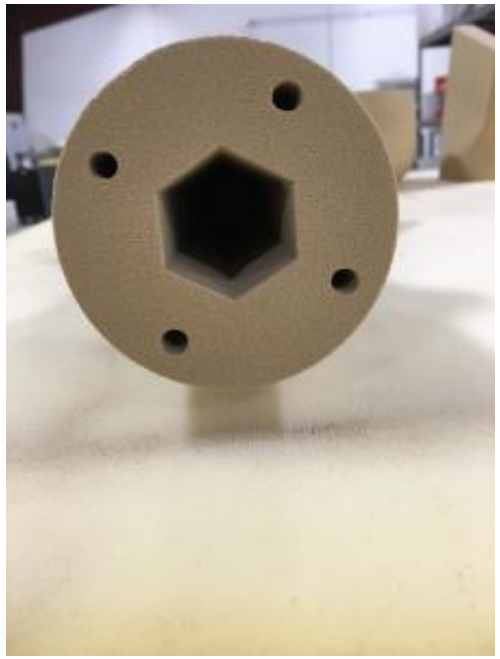
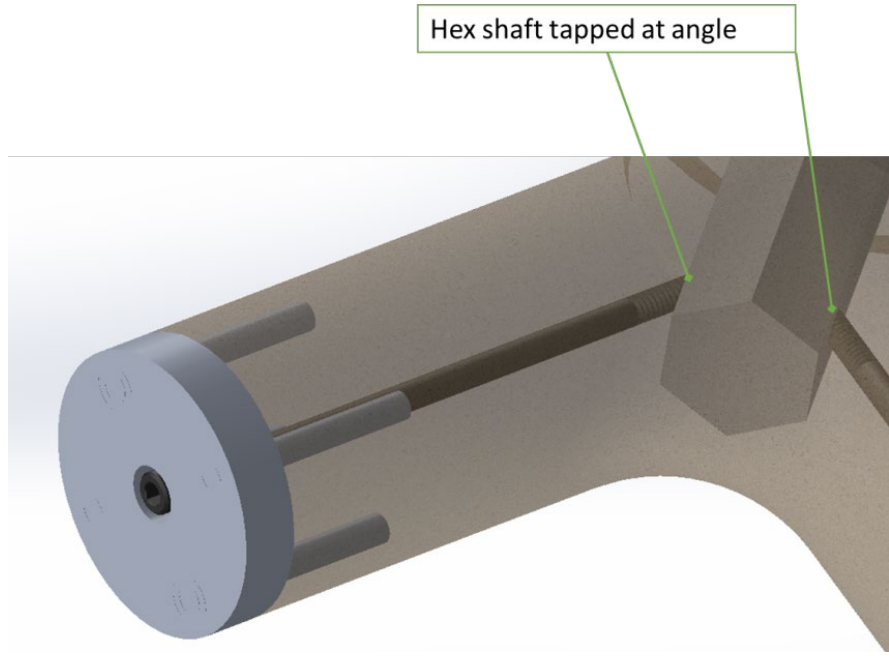
Integration with Metallic Hardware

Printed Cerabeads® washout mandrel (Teflon wrapped) with integrated hardware





Washout Tooling | Material Properties

Specifications on materials and processing capabilities

Material Property	ExOne Washout Tooling	
	Silica sand	Ceramic Sand
Density	1.44 g/cm^3 (90 lbs/ft^3)	1.52 g/cm^3 (95 lbs/ft^3)
Max use temperature	180C (350F)	180C (350F)
Coefficient of Thermal Expansion- RT to 180C (RT to 350F)	20 ppm/°C (11 ppm/°F)	3 ppm/°C (2 ppm/°F)
Compressive Strength	>3.45 Mpa (500 PSI)	>3.45 Mpa (500 PSI)
Tolerance	+/- 0.5 MM (0.020")	+/- 0.5 MM (0.020")
Coating Options	Teflon tape wrap of spray on-soluble coating	
Washout Methods	Room temperature tap water	

Washout Tooling | Comparing Methods

High-quality manufacturing in our St. Clairsville, Ohio, facility

Technology	NRE Cost	Build Cost	Build Time	Tooling Req'd	Use Temp	Removal	CTE	Use Driver
Binder Jetting	$	$	Low	No	180° C	Tap water	Low or High	New technology
FDM (SSYS)	$	$$	Med	No	180° C	Hot solvent	High	New technology
Plaster / Castable Media	$$	$	Low*	Yes	120° C	Breakout	Med	High Quantity, Legacy, inexpensive
Bladder Molding	$$$	$$$	High	Yes	>180° C	Deflate	High	High quantity, OML & IML control
Breakdown Tooling	$$$	$$$	High	Yes	>180° C	Multi-pc	High	High quantity

After tooling is made

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ExOne Capabilities | Quality Control

Experienced mission-critical manufacturing team

ISO-Certified and ITAR Compliant: Quality Control Process for Washout Builds

- Multiple test bars printed in every build
- Bars are tested for:
  - Bend strength (Foundry Standard)
  - Solubility
  - Dimensional accuracy

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ExOne Capabilities | Full Inspection

Experienced mission-critical manufacturing team

All washout mandrels are scanned and inspected to ensure the parts meet the tolerance of the 3D model.

Q&A

STAY TUNED: The next Session on X1 Tooling for Metal begins at 3 p.m. ET