EXONE SAND BINDER JET 3D PRINTING

ABOUT EXONE

About ExOne

ExOne is the pioneer and global leader in binder jet 3D printing technology. Since 1995, we've been on a mission to deliver powerful 3D printers that solve the toughest problems and enable world-changing innovations. Our 3D printing systems quickly transform powders – including metals, ceramics, composites and sand – into precision parts, metalcasting molds and cores, and innovative tooling solutions.

Learn more about ExOne at www.exone.com or on Twitter at @ExOneCo. We invite you to join with us to #MakeMetalGreen™

The ExOne Company | Overview

The global leaders in binder jet 3D printing for 20+ Years

Founded

- Began in 1995 as the 3D division of Extrude Hone
- Around 270 employees worldwide
- NASDAQ listed since 2013

Machines & Services

- Industrial-grade binder jet 3D printing systems and services
- 3D printing solutions for sand, metal, ceramics and composites

High-Value Parts

- Sand molds and cores
- Direct metal 3D printing
- Direct ceramic 3D printing
- 3D printed tooling solutions

Industrial Markets

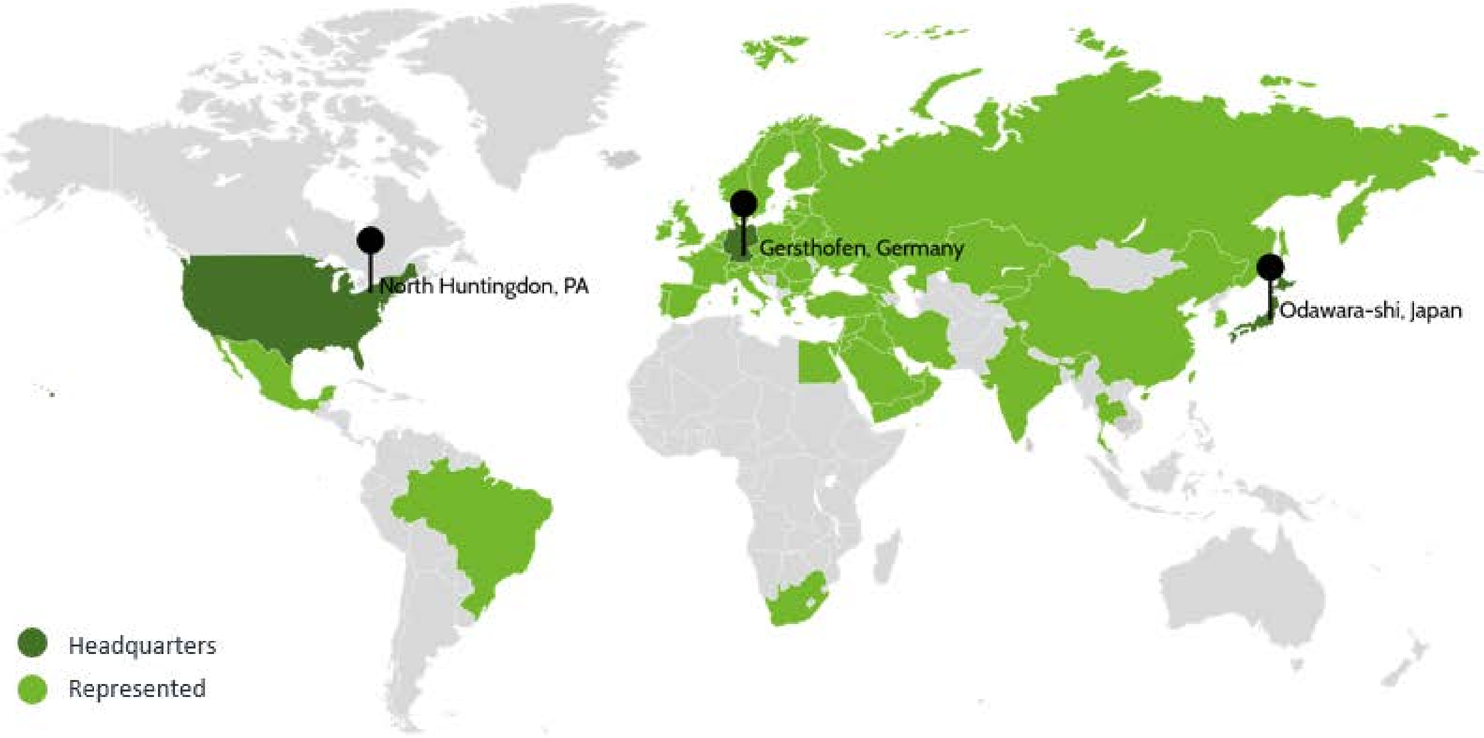
- Foundries | Automotive
  Aerospace | Defense | Medical
  Energy | Heavy Equipment
  Architecture | Construction

Rapid Growth

- 2018 Revenue: $65M
- 3-year annual growth: 17%
  Transitioning from R&D and prototyping to production

The ExOne Company | Locations

We are represented all over the world



Headquarters

The ExOne Company
127 Industry Boulevard
North Huntingdon, PA 15642
USA

ExOne GmbH
Daimlerstrasse 22
86368 Gersthofen
Germany

ExOne KK
161-5 Haneo
Odawara-shi, Kanagawa
Japan

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The ExOne Company | Early Years

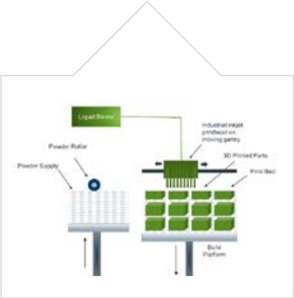
Highlights of an emerging technology leader

1995

The Vision
Extrude Hone creates the "ProMetal" division to develop 3D printing. Company founder Larry Rhoades sees the potential of the new technology.

1996

The Patent
Extrude Hone obtains exclusive field-of-use license for patented 3D printing processes developed at the Massachusetts Institute of Technology (MIT).



1998

The Pioneer
Launch of the ProMetal RTS-300, the first metal 3D printer using binder jetting technology and the commercial realization of MIT's invention.

2002

Entry into Sand
Extrude Hone launches the S15 sand printer using binder jet technology.

2003

A Workhorse
Extrude Hone launches the ProMetal R2, one of the company's most robust and successful direct metal 3D printers using binder jet technology.

2005

Year of the Spin-off
Extrude Hone launches two new printers, the S-Print sand printer and X1 Lab metal printer and is sold to Kennametal. The assets of the 3D printing business are transferred to a newly created entity: "The Ex One Company."

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The ExOne Company | A New Era

Highlights of an emerging technology leader

2007

Unexpected Change

Rhoades dies unexpected and ExOne is purchased by a company wholly owned by S. Kent Rockwell, who has led the company ever since as Chairman of the Board of Directors.

2010-2013

The Printers

Launch of four all-new printers: the S-Max, a new version of the S-Print, now a staple portfolio product, and the M-Print and M-Flex metal printers.

2013

Breakthrough R&D

ExOne begins 3D printing full-density single alloy metals without infiltration – a game-changing technology breakthrough.

The XONE IPO

ExOne successfully completes its Initial Public Offering on Nasdaq, one of the most successful IPOs of the year. Shares of XONE begin trading.

2014

Waves of Sand

ExOne launches three new sand printers, including a new S-Max and S-Print models, continuing its market share gains in sand 3D printing.

2018

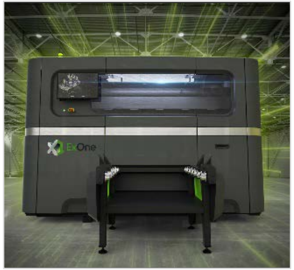
New Metal Era

ExOne launches the X1 Innovent+ and X1 25PRO metal 3D printers for processing ultra-fine MIM metal powders into dense single alloy parts without infiltration.

2019

The Next Generation

ExOne launches the S-Max Pro production sand 3D printer and the X1 160PRO, the company's tenth metal printer and the industry's largest commercially available metal binder jetting system.



ExOne Delivers

Experienced provider of metal binder jetting systems

SHIPPING SOON | The X1 160 Pro™

Our tenth and largest metal 3D printer
Build Dimensions: 800 x 500 x 400 mm
(31.5 x 19.7 x 15.8 in)

Announced: Formnext 2019 | Delivery: 2H 2020

ExOne Machine History

		Material Type				Build Area Dimensions*				Details	
		Sand	Metal	Ceramic	Composite	X	Y	Z	volume	Launch Year	Status
21	InnoventPro®		X			4.9 in (125 mm)	8.7 in (220 mm)	3.9 in / 7.9 (100/200 mm)	3L or 5L	2021	Coming Soon
20	X1 160Pro™		X	X	X	31.5 in (800 mm)	19.7 in (500 mm)	15.8 in (400 mm)	9,763 cu in (160 cu dm.)	2020	
19	S-Max Pro®	X				70.86 in (1800 mm)	39.37 in (1000 mm)	27.56 in (700 mm)*	76,886 cu in (1.26 cu m.)	2019	
18	X1 25Pro®		X	X	X	15.75 in (400 mm)	9.84 in (250 mm)	9.84 in (250 mm)	1,525 cu in (25 cu dm.)	2019	
17	Innovent+		X	X	X	6.3 in (160 mm)	2.56 in (65 mm)	2.56 in (65 mm)	41.3 cu in (676.8 cu cm.)	2018	
16	Innovent		X	X	X	6.3 in (160 mm)	2.56 in (65 mm)	2.56 in (65 mm)	41.3 cu in (676.8 cu cm.)	2016	
15	Exerial	X				86.61 in (2200 mm)	47.24 in (1200 mm)	27.56 in (700 mm)	112,760.5 cu in (1,848 cu m.)	2015	Discontinued
14	S-Max+Silicate	X				70.9 in (1800 mm)	39.37 in (1000 mm)	23.6 in (599 mm)	65,875.5 cu in (1.08 cu m.)	2014	Discontinued
13	S-Max+Phenolic	X				70.9 in (1800 mm)	39.37 in (1000 mm)	23.6 in (599 mm)	65,875.5 cu in (1.08 cu m.)	2014	Discontinued
12	S-Print Silicate	X				31.5 in (800 mm)	19.68 in (500 mm)	15.75 in (400 mm)	9,763.7 cu in (160 cu dm.)	2014	
11	M-Flex	X	X	X	X	15.75 in (400 mm)	9.84 in (250 mm)	9.84 in (250 mm)	1,525 cu in (25 cu dm.)	2013	
10	S-Print Phenol	X				31.5 in (800 mm)	19.68 in (500 mm)	15.75 in (400 mm)	9,763.7 cu in (160 cu dm.)	2012	
9	S-Print Furan	X				31.5 in (800 mm)	19.68 in (500 mm)	15.75 in (400 mm)	9,763.7 cu in (160 cu dm.)	2012	
8	M-Print	X	X			31.5 in (800 mm)	19.68 in (500 mm)	15.75 in (400 mm)	9,763.7 cu in (160 cu dm.)	2012	Discontinued
7	S-Max Furan	X				70.9 in (1800 mm)	39.37 in (1000 mm)	27.56 in (700 mm)	65,875.5 cu in (1.26 cu m.)	2010	
6	S-Print	X				31.5 in (800 mm)	19.68 in (500 mm)	15.75 in (400 mm)	9,763.7 cu in (160 cu dm.)	2005	
5	X1-Lab		X			1.5 in (38 mm)	2.3 in (58 mm)	1.3 in (33 mm)	4.5 cu in (73 cu cm.)	2005	Discontinued
4	R2		X	X		7 in (178 mm)	7 in (178 mm)	5 in (127 mm)	245 cu in (4 cu dm.)	2003	Discontinued; Still being used for production
3	S15	X				59 in (1499 mm)	30 in (762 mm)	28 in (711 mm)	49,560 cu in (812 cu dm.)	2002	Discontinued
2	R10		X			36 in (914 mm)	18 in (457 mm)	12 in (305 mm)	7,776 cu in (127 cu dm)	1999	Discontinued
1	RTS-300		X			11.8 in (300 mm)	11.8 in (300 mm)	9.8 in (249 mm)	1,364.6 cu in (22 cu dm.)	1998	Discontinued

Some systems may also have additional build box sizes and configurations.

**"Machine Results". Senvol. Retrieved 2019-06-26.*

The ExOne Company | Installed 3D Printers

Number of installed 3D printers worldwide

167 Sand

145 Metal

312 * MACHINES WORLDWIDE

AMERICA

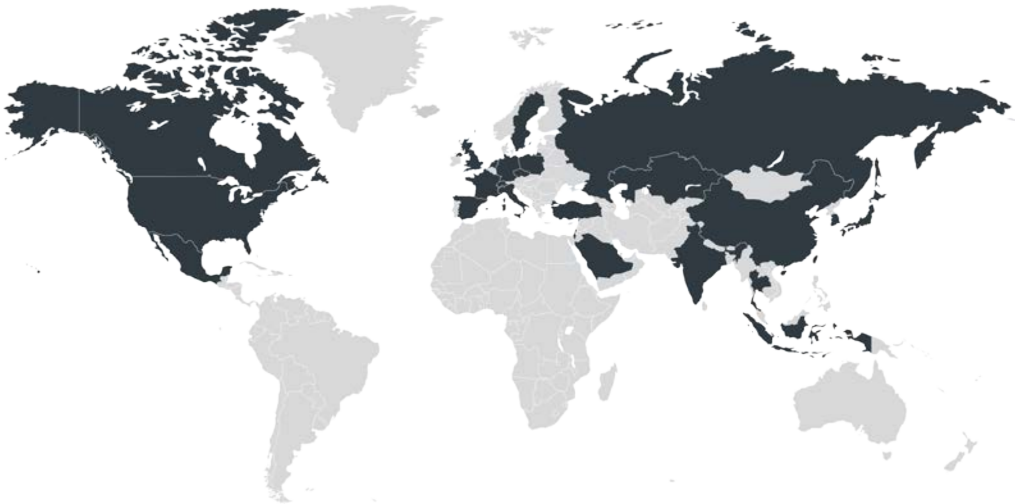
Country	Metal	Sand
United States	90	29
Canada	7	2
Mexico		5

ASIA

Country	Metal	Sand
Japan	10	32
China	4	21
India		7
Indonesia		1
Saudi Arabia	0	1
Singapore	3	
South Korea		3
Thailand		1

EUROPE

Country	Metal	Sand
Germany	12	20
Czech Republic	2	2
France	2	4
Great Britain	1	8
Israel	1	
Italy	1	8
Kazakhstan		1
Liechtenstein	1	
Netherlands		1
Spain	3	1
Sweden	5	2
Switzerland		4
Turkey		3
Russia	1	11
Poland	2	0



* sold machines as of Q2 2020

ExOne | Our Collaboration Partners

Critical research and development network

Amy Elliott, PhD Research Scientist, Oak Ridge National Laboratory ORNL

Altair

ANSYS

ELNIK SYSTEMS

KENNAMETAL

OAK RIDGE National Laboratory

SANDVIK

SIEMENS

ExOne has a growing number of collaborations that enable us to develop binder jet technology faster.

These relationships, often made with customers, help us develop faster by working with us in a variety of areas:

- Materials
- Software
- All-New Applications
- Optimizing Applications
- Research Studies
- Binder Jetting Processes
- Binder Jetting Accessories

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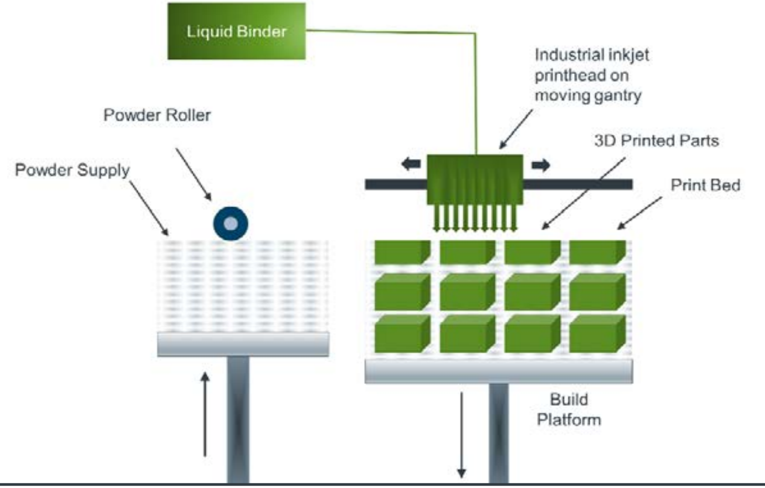
OUR CORE TECHNOLOGY

ExOne | Our Core Binder Jetting Technology

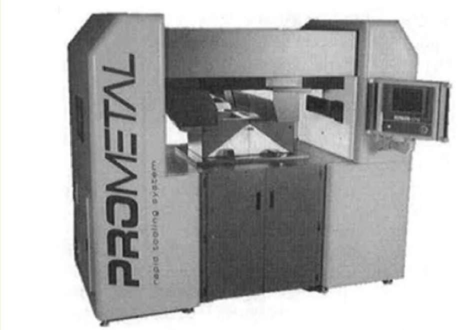
Binder Jet 3D Printing Leadership for 20+ Years



Definition: A method of 3D printing in which an inkjet print head quickly deposits a bonding agent onto a thin layer of powdered particles, either metal, sand, ceramics or composites. This process is repeated, layer-by-layer, using a map from a digital design file, until the object is complete.

For metals, this process creates a "green" part that is then cured, or dried, in an oven. The part is then "depowdered" or removed from the powder bed and cleaned before final sintering in a high-temperature furnace, where the particles fuse together.

Initially developed at the Massachusetts Institute of Technology in the early 1990s, ExOne obtained the exclusive license to this inkjet-in-powder-bed approach in 1996. **Two years later, in 1998, ExOne launched the market's first commercial binder jet metal 3D printer, the RTS-300.**



Binder Jetting | Overview

Patented in 1993 by Massachusetts Institute of Technology

POWDER

Sand, Metal, Ceramics, Composites

BINDER

Liquid binder adheres powder and layers together

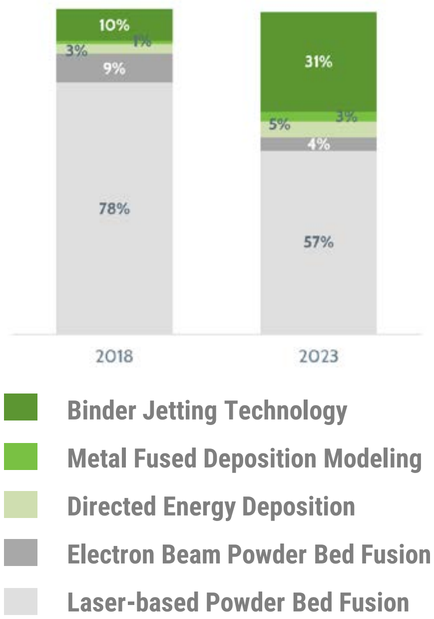
PRINT EACH LAYER

- 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



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Binder Jetting | 3D Printing Process Overview

Liquid binder is applied to a layer of powder to form high-value parts and tooling

Digital File Prep → Machine & Material Prep → 3D Printing

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

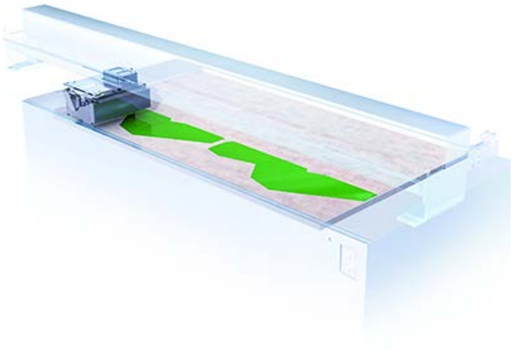
ITERATIVE PROCESS WITH BIG PAYOFFS

ExOne | Binder Jetting Technology

Binder is selectively applied to a thin layer of sand, layer by layer, to form parts

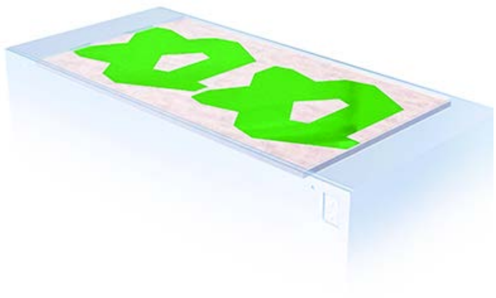
START LAYER

The recoater applies the first thin layer of powder – either sand, metal, ceramics or another material – into the print area or job box.



INKJET BINDER

A gantry of industrial print heads selectively applies binder to the powder to bind particles together where desired.



FAST LAYER SPEEDS

With a full sweep of print heads, a binder jet 3D printer can complete a full layer very quickly. This is one of the core benefits of binder jetting compared to other 3D printing methods.

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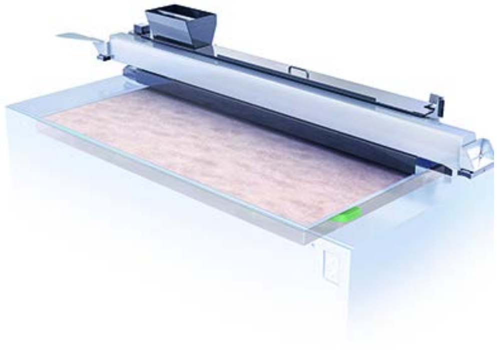
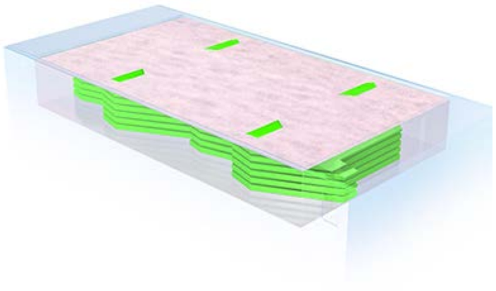
ExOne | Binder Jetting Technology

Precise recoating of sand, and application of binder, are key for quality parts



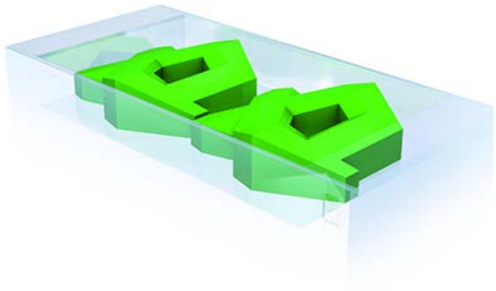
RECOATING

This is a critical step in the binder jetting process, when the recoater lays down the next layer of powder. It must be precisely and compactly applied to deliver a high-qualify precision part.



RINSE AND REPEAT

Once the next powder layer has been applied to the print area, the stage has been set for the next layer of binder. This recoating-and-binding sequence is repeated until the part is complete.



POST PROCESSING

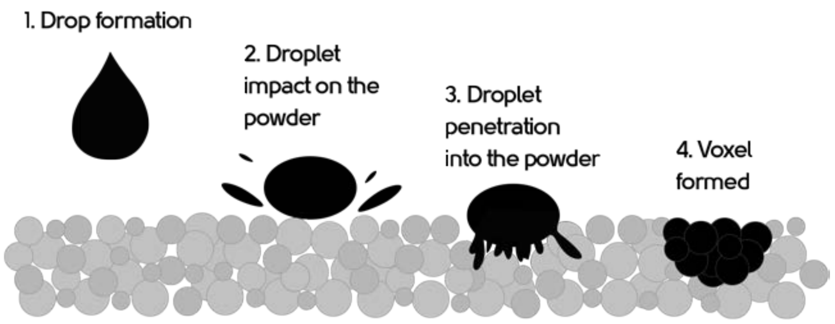
Once the job is complete, the part is removed from the bed of sand and may need to be cured in an oven or microwave, depending on the sand and binder selected. Metal parts need an additional step of sintering to fuse the particles together.

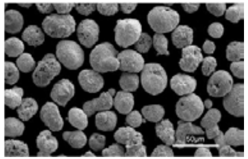
ExOne | The Binder Jetting Process

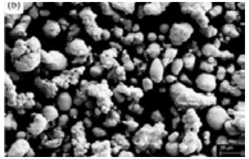
Dropping inkjet into a bed of powder takes extreme engineering and experience to control

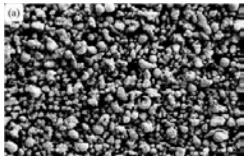
Among the Challenges

- Precisely jetting fine droplets of binder fluid into a bed of powder where particles are not necessarily the same size and shape (not perfect rounds, D50 variations) is challenging in X, Y and Z
- Ink must be dropped precisely in the X and Y directions and not bleed in the powder
- Ink must seep vertically around various particle sizes and shapes (depending on material) to a controlled Z-depth
- Powder must be spread on top of existing print layers to a controlled depth across the entire build area and compacted tightly for green-part density
- Binder must cure between layers to prevent spreading new particles on wet particles
- The process must be repeatable and deliver consistent results across the entire build area









Learn More
www.exone.com/binderjetting

ExOne | We Turn Powder into Parts

Binder jetting a wide range of powder materials

POWDER MATERIALS WE PROCESS

SAND

Industrial Sands for metal casting

EX: Silica sand, ceramic sands, and more ...

METAL

Ultra-fine metal MIM powders

EX: 316L, 304L, 17-4PH, and more ...

CERAMICS

Wide variety of ceramic powders

EX: Silicon carbide and more ...

COMPOSITES

Industrial-grade composites

EX: Tungsten Carbide Cobalt and more ...

ExOne™

ExOne | Binder Jetting Materials

20+ qualified 3D printing powders plus another 25 R&D materials

ExOne Binder Jet 3D Printing Materials

Q4 2020

3D Printers	sands	ceramics	composites	100% metals	build volume	applications
X1 160Pro		✓	✓	✓ >97% Density with TRIPLE ACT	XL	• Serial Production Low or High Volumes • MIM-Like Parts • Prototypes • R&D
X1 25Pro		✓	✓	✓	L	
Innovent+ or Pro	✓	✓	✓	✓	S/M	
M-Flex	✓	✓	✓	✓	L	• Metalcasting Molds & Cores • Sustainable Tooling • Production Low or High Volumes • Prototypes • R&D
S-Print	✓	✓			XL	
S-Max	✓	✓			XXL	
S-Max Pro	✓	✓			XXL	
TWENTY+ QUALIFIED 3D PRINTING POWDERS	2 SAND TYPES: Natural and Synthetic Sands	4 CERAMICS: Alumina, Carbon, Silicon Carbide, Tungsten Carbide Cobalt	5 COMPOSITES: 316 w/Bronze, 420 w/Bronze, Boron Carbide w/Aluminum, Silicon Carbide w/Silicon, Tungsten with Bronze	11 METALS: 17-4PH, 304L, 316L, Cobalt Chrome, Copper, H13 Tool Steel, Inconel 718, Inconel 625, M2 Tool Steel, Titanium, Tungsten Heavy Alloy	SUSTAINABLE MANUFACTURING TECHNOLOGY	

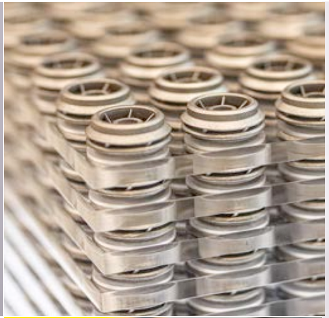
The twenty+ materials listed above have been qualified for use on ExOne machines by ExOne, our customers and independent third parties.

Plus, another 25 R&D materials – including aluminum and more

ExOne

Binder Jetting | Print, Pour and Produce

A flexible array of materials for direct printing complex, high-value parts and tooling




Binder Jetting | Four Primary Application Categories

Binder Jetting delivers complex, high-value parts faster, with a dramatic reduction in waste

3D sand molds and cores for metal casting

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 | Transformational Benefits

Faster delivery, done-in-one pieces, new design freedoms and business flexibility

While all forms of 3D printing deliver some of these benefits, only binder jetting can deliver the throughput necessary to drive high-volume transformation.

SPEED

- High volumes at high speeds
- Hours and days versus weeks and months
- Rapid design iterations without $$ hard tooling
- Beat competitors to market

WASTE REDUCTION

- Reduce or eliminates a wide range of wastes
  - Material waste
  - Hard tooling
  - Excess mfg processes
  - Inventory
  - Labor (reduce or eliminate excess assembly)

SAVINGS

- Saves costs by streamlining many forms of wastes
  - Waiting
  - Defects
  - Over-processing
  - Overproduction (no min. volumes)
  - Transportation and storage of parts to assemble

DESIGN FREEDOM

- Sustainable manufacturing without traditional limitations
- Consolidate parts into monolithic parts
- Lightweight part designs in trusted materials
- New rigging, riser and other designs for metalcasting molds for done-in-one pours
- All new innovative products not previously possible
- Easy to iterate designs

FLEXIBILITY

- Some binder jet systems can print many different materials (industrial-grade or MIM powders)
- Print or Pour: Binder jetting systems can direct print final parts and tooling for metalcasting & more
- From prototyping to production: Binder jetting is currently best suited for production volumes and can also accommodate tooling
- Enables decentralized manufacturing

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ExOne | Eliminating Costly Waste

3D printing eliminates wasted time and resources, improving profitability

Kaizen 改善

The ultimate lean tool

Binder Jet 3D printing addresses all of the eight types of waste recognized in lean business principles.

Waste is the root of all unprofitable activity, according to Kaizen lean philosophy.

Lean production is focused on reducing and eliminating waste.

Waiting
No waiting for patterns, molds, pours or parts

Overproduction
No minimum volume requirements

Overprocessing
Reduce processing and assembly steps

Defects
Eliminate stack-up errors, reduce defects

Motion
Reduce unnecessary movement (assembly)

Inventory
Eliminate many forms of inventory

Transportation
Reduce shipping materials and parts

Skills
Inefficient use of people doing low-value task

Metal 3D Printing | Exceptional Design Freedoms

Complexity achievable in final part as well as rigging and riser design

ExOne and Altair worked with a global automotive manufacturer to lightweight an existing structural truck part that holds cruise control sensors.

The existing part was redesigned with Altair Inspire and 3D printed with ExOne binder jetting in 316L stainless steel.

BENEFITS

- More than 45% lighter
- Fewer manufacturing processes to make
- Reduced the amount of welding required to affix the part to the vehicle structure

Altair

ExOne

BINDER JETTING CONSIDERATIONS

Binder Jetting | A Simple Process with Interdependency

Dropping inkjet into a bed of powder takes extreme engineering and experience to control

PRINTHEAD

- Binder must be dropped precisely in the X and Y directions, with controlled levels of bleeding and saturation in Z

POWDER

- Powder particles vary in size and shape (not perfect rounds, particle size variations), and oxidation sensitivity, so powder needs to be characterized and conditioned prior to printing

BINDER

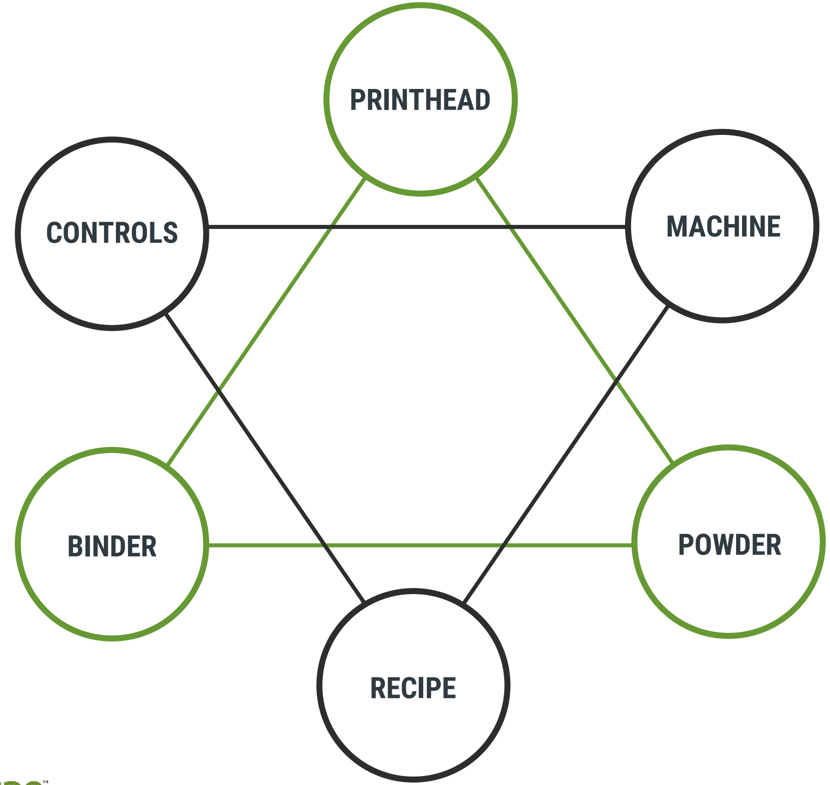
- Droplet size and properties (chemistry, rheology, ink, glue and coating properties) must adapt to material characteristics. Must be able to "dry" quickly between layers for quick binding and application of next layers without wet powder smearing

CONTROLS & MACHINE

- Tight controls of the mechanicals necessary to ensure precise powder dispensing, spreading and compact, as well as printing

RECIPE

- Process must be optimized for all powder-binder combinations and deliver consistent and repeatable results across the entire build area



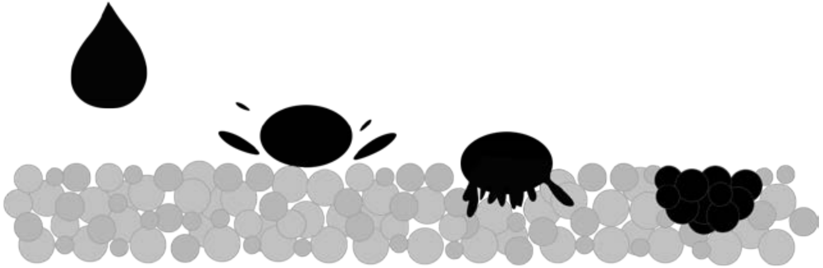
Binder Jetting | Powder Characterization

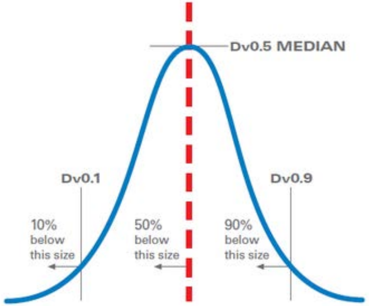
Powder must be characterized and conditioned and work well with selected binder

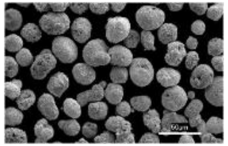
Large Particle Powders (60 microns) → Finer Particle Powders (30 microns) → MIM Powders (<30 microns) → Multiple MIM Powders

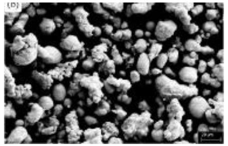
UNDERSTANDING POWDER CHARACTERIZATION

- Important to understand the powder on which you're printing for successful outcome
- While high-density metal is achievable today, you may want bonded, partially sintered, or infiltrated parts for some applications
- Particle size distribution D50 is also known as the median diameter of the particle size distribution. It is the value of the particle diameter at 50% in the cumulative distribution. It is one of the most important features of characterizing powder.
- Particle shape and surface textures
- Bulk and tap densities of the powder
- Rheology characteristics such as powder cohesiveness









ExOne

Metal 3D Printing | Applications by Porosity

From large particles to infiltrated materials to dense, single-alloy, ultra-fine powders

Coarse Powders

Product Forms

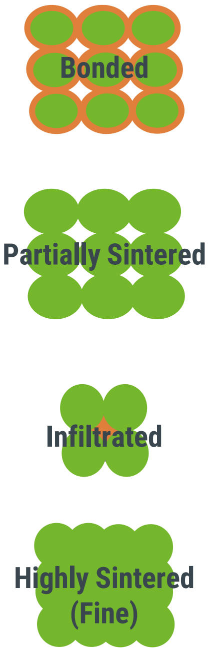
Materials (D50>20µ): Minerals, Ceramic, Carbon, Glass, Ceramic, Metal

Markets:

- Sand casts molds
- Low density single-alloy parts < 90%, Filters
- Metal and ceramic matrix
- Other course powder non-metallics
- Castings - high density single-alloy
- Tooling

Fine Powders

Product Forms



Materials (D50 <20µ): Minerals, Ceramic, Glass, MIM, CIM powders

Markets:

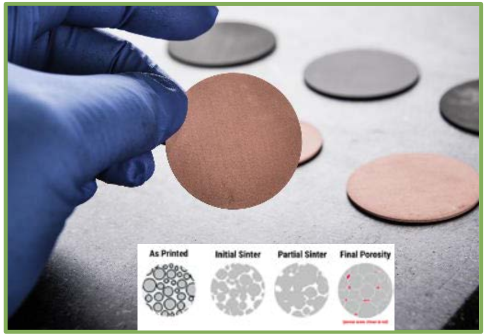
- MIM
- CIM
- Investment castings
- Machined parts
- PM parts
- Ceramic matrix
- Cutting tools
- Wear parts

Bonded

Partially Sintered

Infiltrated

Highly Sintered



ExOne

Binder Jetting | Binder Considerations

Many binders are proprietary to manufacturers and play a critical role

CHEMISTRY REQUIREMENTS

- Compatible with jetting module
- Compatible with powder
  - Must wet powder while limiting bleeding and seeping to desired depth for stitching
  - Must not ruin powder (like acid/rust)

SAFETY

- Safe to handle, ship and dispose of or recycle
- Pure or clean.
  - Filtered below 3 microns
  - DI / Distilled Water

BINDER RHEOLOGY

- Viscosity
- Surface Tension

BINDER PROPERTIES

- Open Time
- Droplet Formation Time
- Stability (doesn't change over time)
- Low or no foam

COATING PROPERTIES

- Film Former
- Matrix Former

INK PROPERTIES

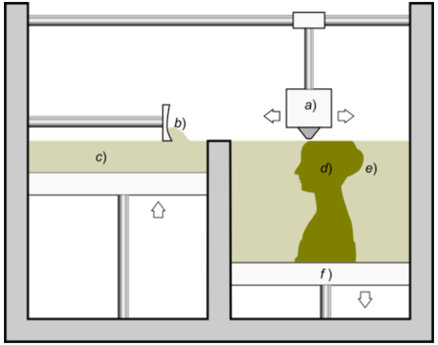
- Detergency
- Adhesive to Surface
- Cohesive to Self
- High-Temperature Functioning

Binder Jetting | Machine Design & Control System

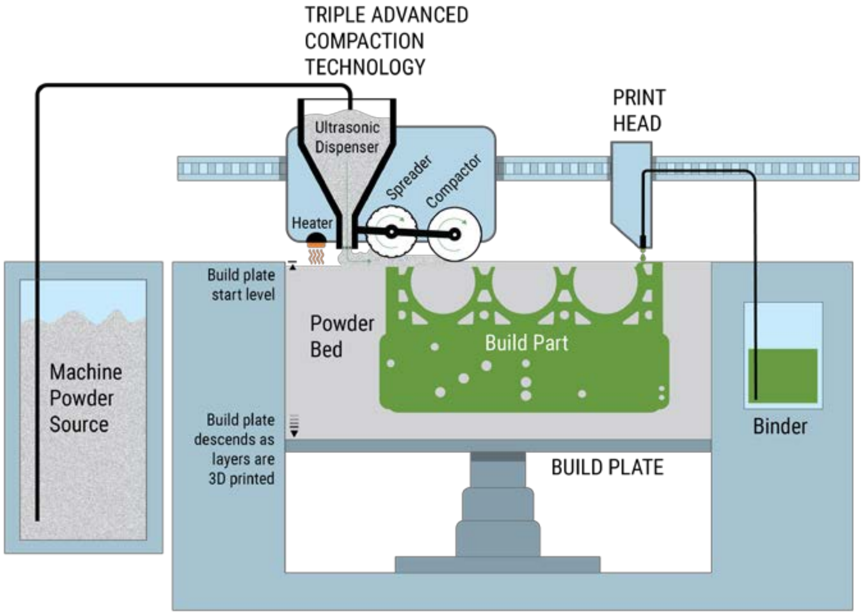
Different binder jet approaches to powder and binder management

Original Approach

- Important to understand different designs and how they impact powder management, cleanliness (a serious consideration with powder) as well as impact on speed and other factors
- Important to consider control systems, sensors, part wear, waste management, recyclability features, accessibility/greenhouse and more



New Approach



Binder Jetting | Recipes & Optimizing with Iteration

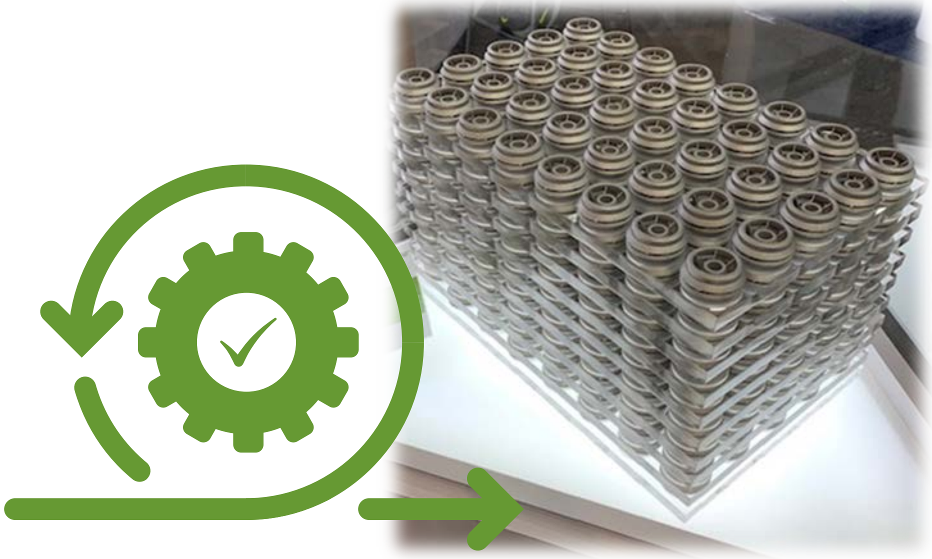
Users can tap high-throughput 3D printing benefits with binder jetting

SAND BINDER JET 3D PRINTING

- The sand printing process and recipes are highly plug and play with little adjustment required
- This process is ready for volume production

METAL BINDER JET 3D PRINTING

- Currently, binder jetting for metals is an iterative design process, where 2-3 prints may be necessary to dial in the parameters. This is largely due to sintering dynamics.
- However, after the iterative process is complete, you can tap the benefits of extremely high throughput and low cost binder jet 3D printing at scale
- Software companies such as ANSYS and Materialise are working to develop software that predicts sintering characteristics and automatically scales and makes recommendations for quality results with less or no iteration



Part: Impeller
Quantity: 400
Build time: 24 hours
Material: 316L

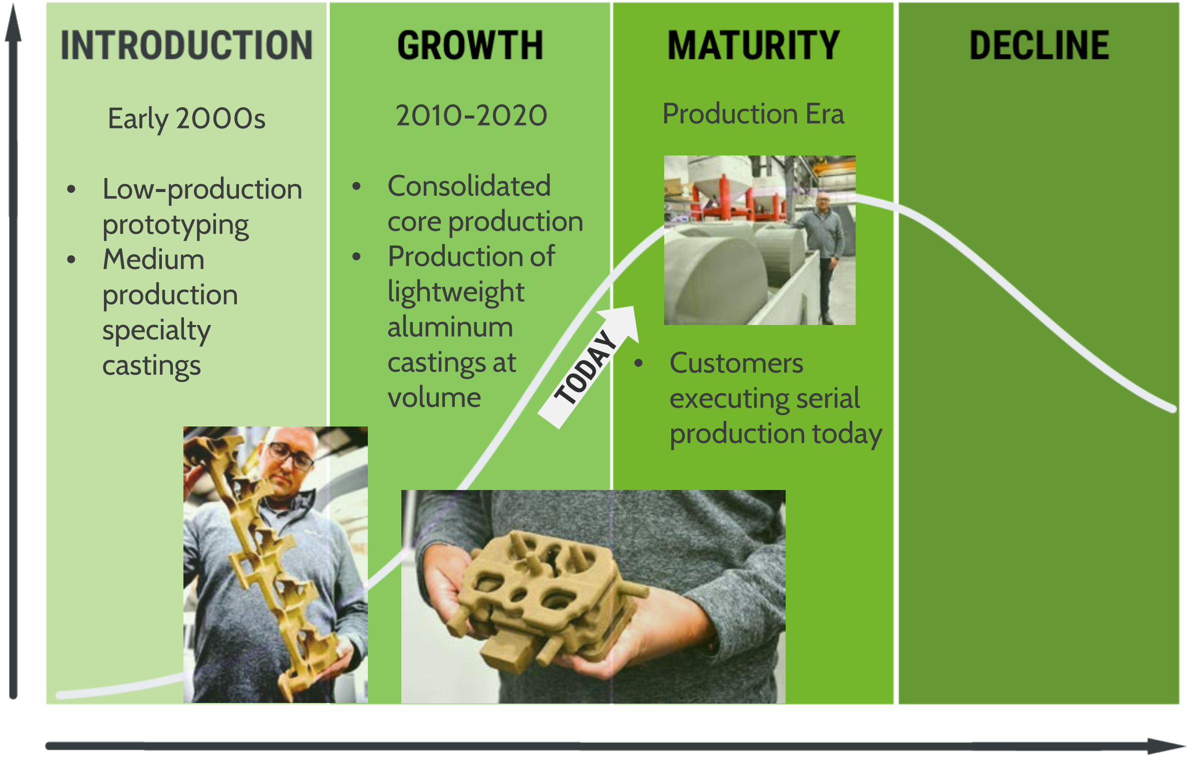
SAND 3D PRINTING

Sand 3D Printing | History

A technology that is now mature and ready for full plug-and-play production

READY FOR PRODUCTION

- Large systems
- High speeds, throughput
- Binder flexibility
- 24/7 Operations
- Automated desanding
- Plug-and-play performance
- Machine-to-machine integration
- Smart monitoring and remote controls
- Inorganic binding for low-emission, aluminum-friendly casting



ExOne

Sand 3D Printing | ExOne Leadership

We are the market share leader in binder jet 3D printers for sand and ceramic media

BINDER JET 3D PRINTERS

- S-Print, a reliable entry-level system
- S-Max, a large and reliable double job box system
- S-Max Pro, our fastest and smartest large sand 3D system

APPLICATIONS

- Sand molds and cores for sandcasting, a metal casting process that uses sand as the mold material
- 3D printed sand tooling, including innovative washout tooling and tooling for vacuum- and hydro-forming

SUPPORT SERVICES

- Comprehensive implementation and training
- 3D printed parts on demand – molds, cores, tooling
- OneCast – 360° services for 3D sandcasting
- Design for Additive Manufacturing (DfAM) services
- Custom development for additive manufacturing programs

SAND 3D MOLDS AND CORES FOR METALCASTING

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

INNOVATIVE 3D PRINTED TOOLING SOLUTIONS

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

Sand 3D Printing | Transformational Benefits

Faster delivery times, done-in-one pours and new design freedoms

Benefits for OEMs and foundries. Deliver final done-in-one castings in hours or days, instead of weeks. Save money on patterns, molds and labor. New opportunities in design and services.

SPEED

Fast Delivery Times

- Deliver molds and cores within hours or days. Compared to weeks and months for traditionally manufactured molds and cores
- Regardless of part complexity

SAVINGS

Eliminate patterns, molds and labor

- Deliver complex cores at a lower total cost than with core shooters, which require the added time and expense of mold creation and assembly, which requires labor and added time
- No more repairing cores after extraction from core shooters

NO PATTERN STORAGE

No physical inventory, easy digital storage

- No storage of patterns or molds for core shooters needed
- Eliminate inventory, liberate space and property
- No repair is ever needed for an overused or degraded patter or mold. No more lost patterns

RAPID DESIGN CHANGES

Improve designs without a cost penalty

- Design iterations can be executed extremely quickly without having to scrap existing patterns or create new patterns and molds for core shooters
- This saves time and money and reduces waste. Ultimately, it can result in better designs without limitations and compromises

EXCEPTIONAL DESIGN FREEDOM

For both part design and mold package, delivering high-quality final parts

- 3D printing offers design freedoms in both the part design and also the rigging and riser design, which can deliver a higher quality casting
- 3D printing allows for hyperbolic sprues, additional vents and sand mold and core designs that are more compatible with desirable low-pressure pouring with no extra cost

Sand 3D Printing | Speed & Quality Improvements

New designs are now possible for metal casted products as well as sand molds and cores

Digital Technology Drives out Defects Faster

Analog Process

Time to First Pour

Time to Delivered Part

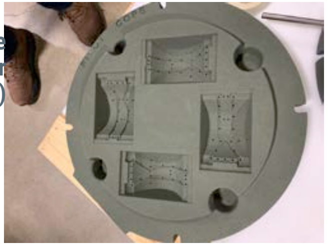
Digital Process

Time to First Pour

Time to Delivered Part

Main Gear Box Transmission First Pour = No defects, part delivered

Done-in-One Pour (Aluminum)



SAND 3D PRINTERS

Sand 3D Printing | Product Overview

Binder jetting for sand molds, cores and new tooling options.

NEW

S-Print

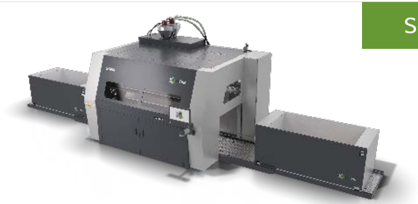
- ✓ Prototyping
- ✓ Rapid product development
- ✓ Short-run Production

A fast, flexible, reliable and compact sand 3D printing machine. Delivering highly accurate complex parts from digital data since 2005.

MAIN SPECIFICATIONS
Build Box (L x W x H): 800 × 500 × 400 mm
Layer Heights*: 0.26 – 0.38 mm

Binder Systems	Furan	CHP	HHP	IOB
Max Build Rate***	up to 39 l/h	up to 17 l/h	up to 15 l/h	up to 25 l/h

S-Max



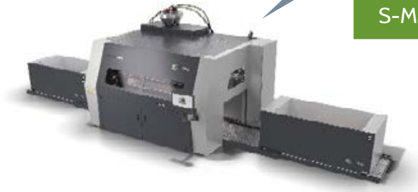
- ✓ Prototyping
- ✓ Rapid product development
- ✓ Short-run production
- ✓ Continuous 24/7 production

A large and robust sand 3D printer known for reliable performance. Double job box option.
Printing cold-hardening binders since 2010.

MAIN SPECIFICATIONS
Build Box (L x W x H): 1800 × 1000 × 700 mm
Layer heights*: 0.26 – 0.38 mm

Binder Systems	Furan	CHP
Max Build Rate***	up to 100 l/h	up to 60 l/h

S-Max Pro



- ✓ Prototyping
- ✓ Rapid product development
- ✓ Short-run production
- ✓ Continuous 24/7 production
- ✓ Processes all ExOne binders
- ✓ Serial Production

Our fastest and smartest large sand 3D printer. All-new automated printhead and recoater. Innovative production features. New in 2019.

MAIN SPECIFICATIONS
Build Box (L x W x H)**: 1800 X 1000 X 700 mm
Layer Heights*: 0.26 – 0.38 mm

Binder Systems	Furan	CHP	HHP	IOB
Max Build Rate***	up to 125 l/h	up to 70 l/h	up to 40 l/h	up to 80 l/h

Depending on material
** *400 mm height with box-in-box system*
*** *depending on Jobbox utilization, sand type, layer height, resolution & environmental conditions*

ExOne

ExOne | S-Print®

A fast, flexible and compact sand 3D printer for a full range of binders

- Prototyping and small series
- Small and compact size
- Can process all ExOne binder systems

TECHNICAL SPECIFICATIONS

External Dimensions: (L x W x H)	3270 x 2540 x 2860 mm (128.7 x 100.0 x 112.6 in)
Build Box: (L x W x H)	800 x 500 x 400 mm (31.5 x 19.7 x 15.8 in)
Layer Heights:	0.26 - 0.38 mm (0.01 - 0.015 in)
Weight:	3500 kg (7716 lbs)
Supply Voltage:	400 V AC (±10%) 3ph/PE/N

Binder Systems:	Furan	CHP	HHP	IOB
Max Build Rate:*	up to 39 l/h	up to 17 l/h	up to 15 l/h	up to 25 l/h
Exhaust Air:	300 m³/h	500 m³/h	500 m³/h	300 m³/h

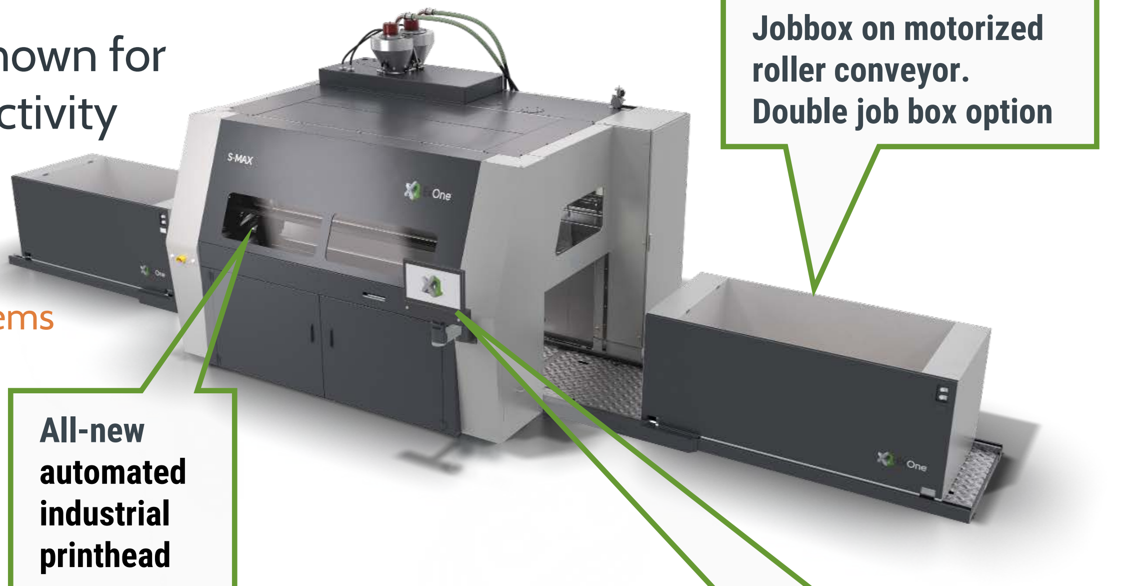
ExOne

** depending on Jobbox utilization, sand type, layer height, resolution & environmental conditions*

ExOne | S-Max®

A large and robust sand 3D printer known for reliable performance and high productivity

- Double Jobbox option
- For continuous 24/7 production
- Ideal for all cold hardening binder systems



TECHNICAL SPECIFICATIONS

External Dimensions: (L x W x H)	10400 x 3520 x 2860 mm (409.5 x 138.6 x 112.6 in)
Build Box: (L x W x H)	1800 x 1000 x 700 mm (70.9 x 39.4 x 27.6 in)
Layer Heights:	0.26 - 0.38 mm (0.01 - 0.015 in)
Weight:	8600 kg
Supply Voltage:	400 V AC (±10%) 3ph/PE/N

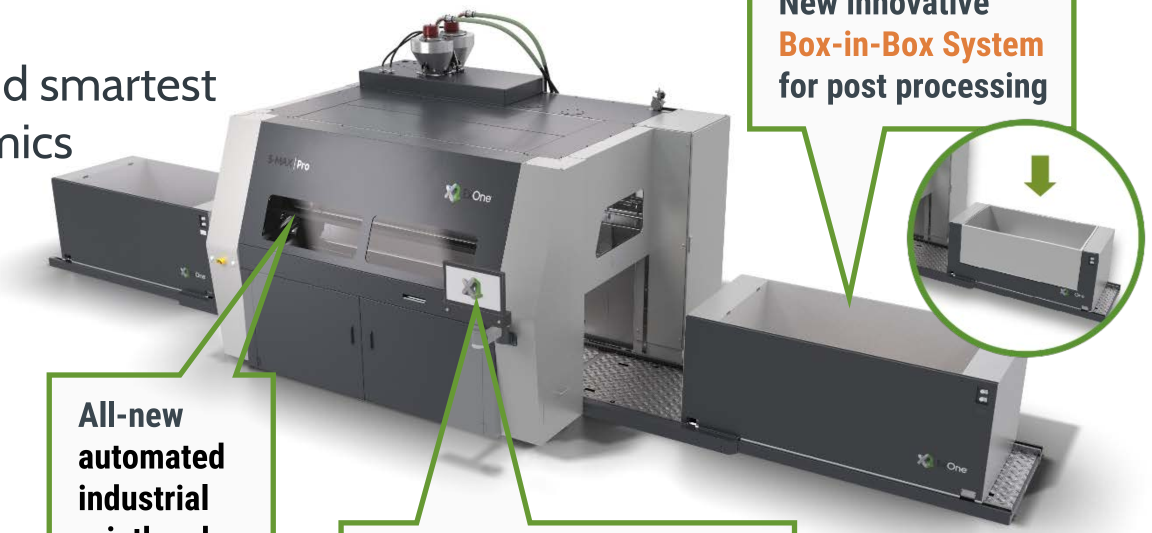
Binder Systems:	Furan	CHP
Max Build Rate:*	up to 100 l/h	up to 60 l/h
Exhaust Air:	300 m³/h	600 m³/h

* *depending on Jobbox utilization, sand type, layer height, resolution & environmental conditions*

ExOne | S-Max Pro™

Built for Production. Our fastest and smartest large 3D printer for sand and ceramics

- Double Jobbox option (for standard jobbox) or Box in Box Jobbox for post-processing steps
- For continuous 24/7 production
- Can process all ExOne binder systems
- Industry 4.0 integration and cloud connectivity
- Real-time process control and increased fault detection capability via camera and app



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Binder Systems:	Furan	CHP	HHP	IOB
Max Build Rate**:	up to 125 l/h	up to 70 l/h	up to 40 l/h	up to 80 l/h
Exhaust Air:	300 m^3/h	600 m^3/h	600 m^3/h	300 m^3/h

With Box-in-Box System 400 mm height

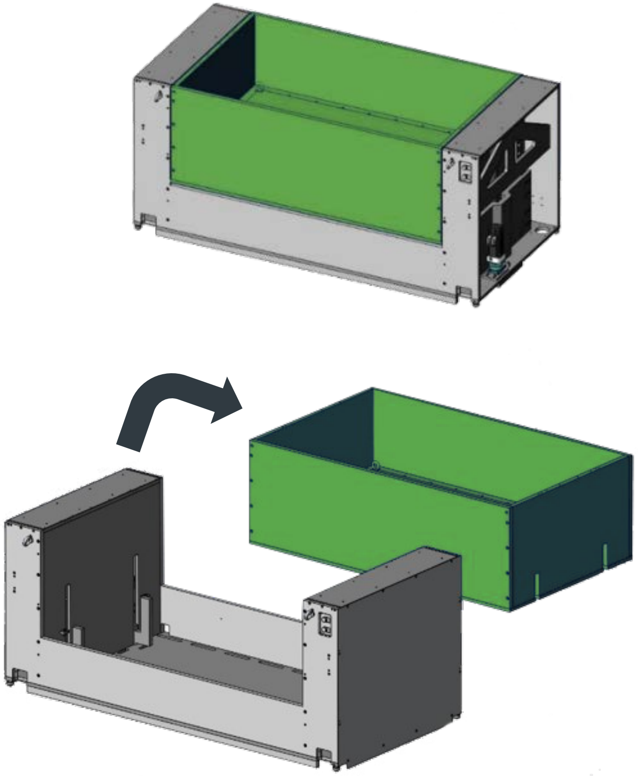
** depending on Jobbox utilization, sand type, layer height, resolution & environmental conditions*

S-Max Pro | Box-in-Box System

Higher machine utilization

Removable box-in-box system

- Leading to an improved performance
- Allowing quick and easy removal of the job immediately after printing
- Machine can start the next job directly → no more downtime of the machine
- Higher usability due to the lower depth of the jobbox
- Box-in-box format (mm): 1800L x 1000W x 400H



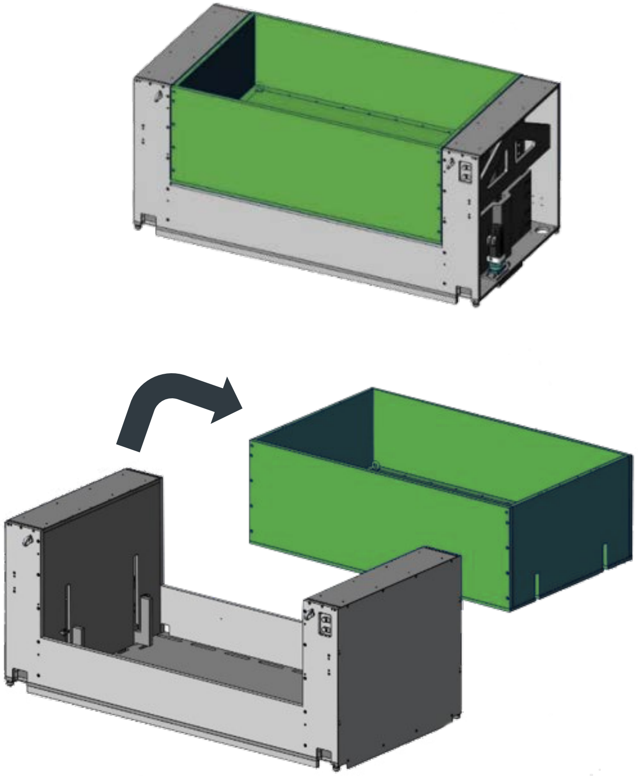
Higher Machine Utilization

S-Max Pro | Box-in-Box System

Multi-binder capable

Removable box-in-box system

- Leading to an improved performance
- Enables printing of all ExOne binder systems (Furan, CHP, HHP, Inorganic)
- Easy Box adaption to different binder systems
- Options:
  - integrated desanding



Multi-Binder Capable

ExOne

S-Max Pro Enabled for Industrial AM production

New Box-in-Box innovation for production

All-new automated industrial printhead and recoater

Latest Siemens Industrial Controller Technology and IoT capabilities enabled by MindSphere © Siemens

Benefits delivered by Siemens Technology

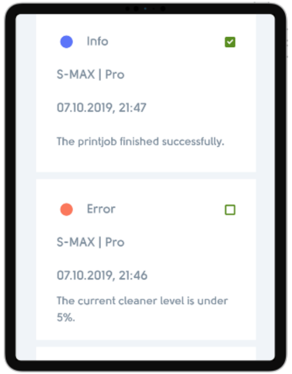
- S-Max Pro (2019) first ExOne 3D printing system featuring Siemens technology
- Digital Twin helped speed software development and testing without physical machine: 30% less engineering efforts
- Integrated hard- and software approach by Siemens: Controls, Drives, HMI, Monitoring systems, Energy Management
- MindSphere © Siemens enabled ExOne to offer new cloud-based services such as Scout app
- Siemens Edge Computing for field data processing highly desired by ExOne customers

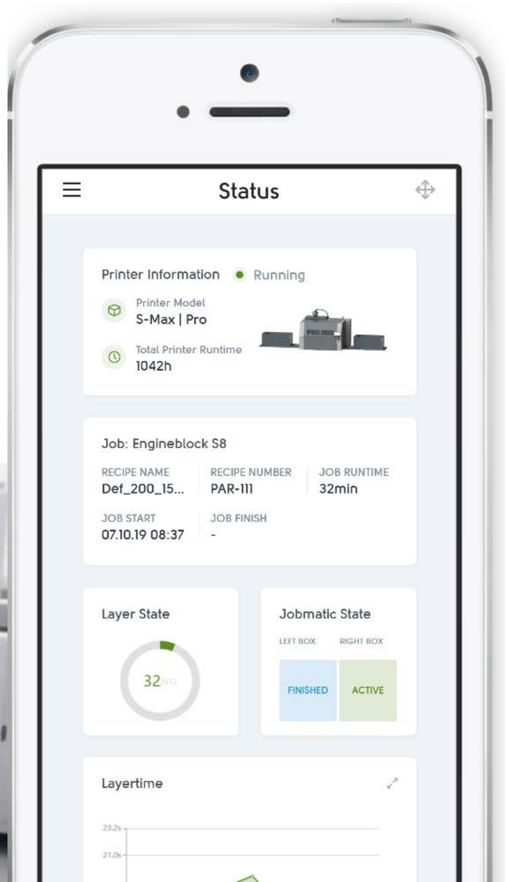
MindSphere fueling ExOne Scout App

Machine monitoring based on the open IoT operating system by Siemens eases management and integration

Integration delivers:

- Real-time insights
- Quality assurance and analysis
- Relevant monitoring metrics and notifications
- Ease of automation integration and management
- App infrastructure enabled by MindSphere©





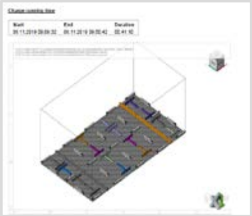
ExOne Quality System Enabled by Siemens

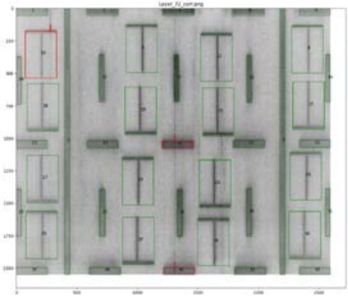
ExOne Quality System Enabled by Siemens

More AI features coming in future

1. Process Monitoring based on Edge Computing

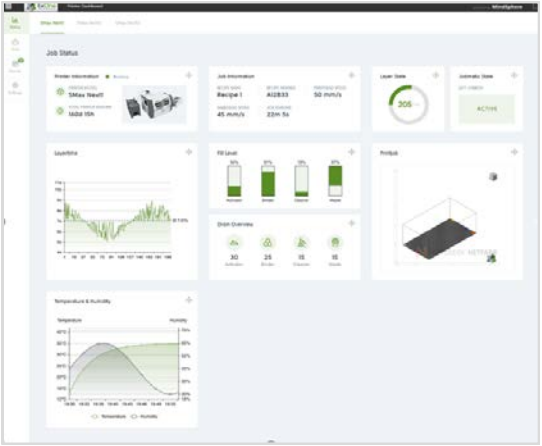
- High volumes of data captured, analyzed, and converted to relevant information pushed to cloud
- Self-learning algorithm evaluates layer pictures in real-time. Can detect defects such as scratches in the powder bed
- Sends ad-hoc quality report





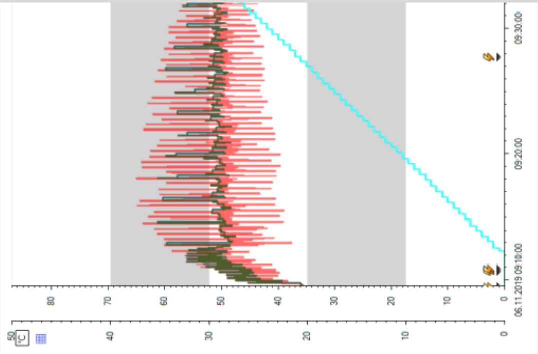
2. Cloud Monitoring with ExOne Scout App

- Live information on active print times, fluid levels, temperature and humidity
- Alerts for out-of-range performance issues or other issues



3. Process Data and Machine State Logging

- Job-to-Job analysis
- Long-term statistics on consumables, temperatures, errors – layer by layer
- Report extraction



Name	Stil	Minimum	Maximum	Durchschnitt	Standardabweichung
Layer		0,000	87,000	40,993	27,387
MachineState					
Temperature Build Area		20,508 °C	35,211 °C	29,403 °C	1,586 °C
Temperature Build Space		20,508 °C	37,381 °C	28,928 °C	2,518 °C
Temperature Ceiling		20,508 °C	35,211 °C	29,403 °C	1,586 °C

ExOne

SAND MATERIALS AND BINDERS

Sand 3D Printing | Binders and Materials

A technology that is now mature and ready for full plug-and-play production

- Organic
- Solvent
- Water
- Inorganic

Print + Microwave or Oven

FB001 – Furan
Steel, iron, non-ferrous metal, aluminum

FB101 – Phenol
(hot hardening HHP)
Steel, iron, non-ferrous metal, aluminum, bronze

FB202 – Phenol
(Cold hardening CHP)
Steel, iron, non-ferrous metal, aluminum, bronze

FB901 – Inorganic
Aluminum

Sand 3D Printing | Binders and Materials

Comparing binder system and molding material compatibility

Molding Material / Binding System	Silica Sand		Synthetic Sand (Cerabeads)		
	FS001	FS003	FS052	FS053	FS054
FB001 (furan resin)					
FB202 (phenolic resin–cold curing)					
FB901 (Inorganic waterglass)					
FB101 phenolic resin hot curing					

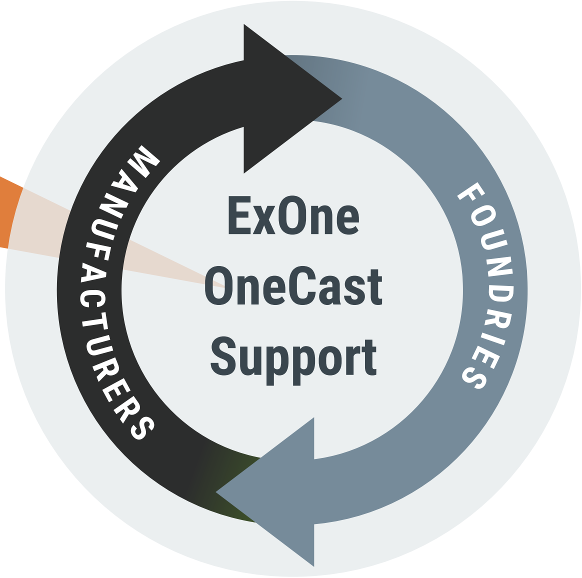
- Standard Process
- Process Not Possible
- Possible Process
- Process is Not Performed

SAND 3D PRINTING SERVICE

ExOne | OneCast Sandcasting Solutions

Full support for sand casting with 3D printing technology

The ExOne OneCast Team has world-class knowledge of metal casting designs and processes for both traditional and 3D printing-enhanced operations.



360° SUPPORT

- Manufacturers
- Foundries
- Pattern Shops
- Designers

ExOne OneCast Services

- Design and Engineering Service
  - Requirements assessment
  - Complete mold and core package design
  - Experienced 3D rigging and riser design services
- Metal Casting Modeling Services
  - Fluid flow and solidification
- Sand 3D Printing Sourcing
- Foundry Sourcing
- Full Inspection Services
- Training
  - Digital mold package design

SAND 3D PRINTING CASE STUDIES

Case Study | German Automaker

Premier auto manufacturer saved 50%+ in costs and gained flexibility for casting design changes

Specifications

Customer: German Automaker

Part: Formula 1 transmission housing

Material Cast: Aluminum Alloy 356

Printed Volume: 200 L for complete mold package

Traditional Method

Method: Patterns and tools for sand core forming, lost foam model parts

Cost Per Lot: 15,000 - 20,000 €

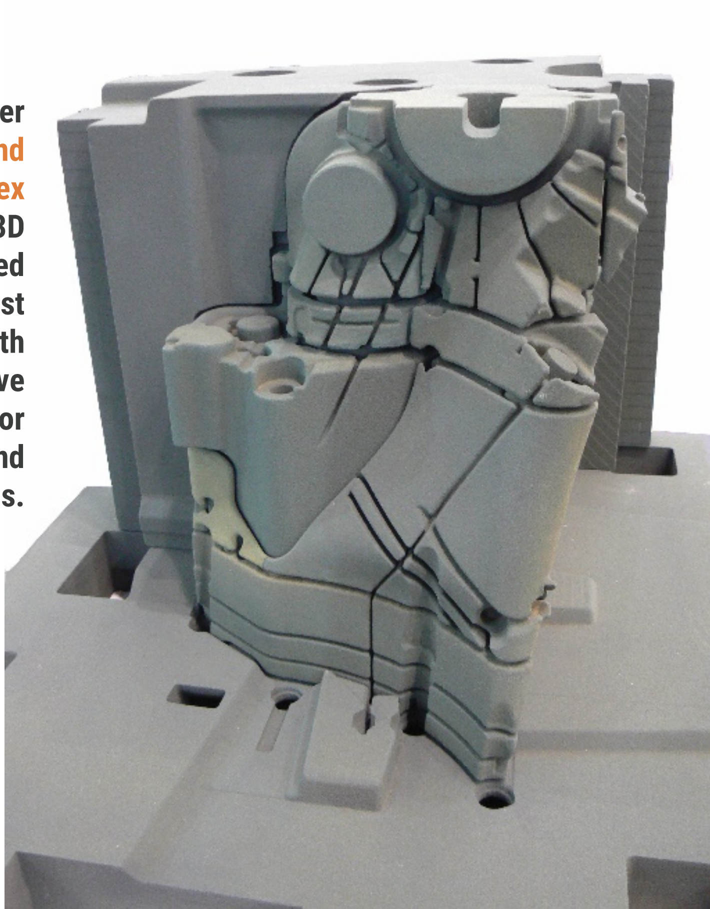
ExOne Sand Printing

Print Media: Silica Sand/Furan Binder

Production Time: 4 hours

Cost Per Part: 1,500 €

Automotive manufacturer needed a way to quickly and economically produce complex prototypes. ExOne's sand 3D printing process offered significant time and cost advantages over both traditional and other additive manufacturing technologies for delivering sand molds and cores for metal castings.



ExOne

Case Study | Neenah Foundry

2019 Casting of the Year, American Foundry Society

3D printed complex core saves thousands in tooling costs, reduces lead time by weeks

Specifications

Customer: Amerequip Corporation

Part: Single ductile iron casting for compact utility tractor component

Material: Ductile iron

Traditional Method

Method: Manufacture core box tooling

Lead time: 6 weeks

ExOne Sand Printing Method using the S-Max Printer

3D Sand Mold Printing and Casting

Print media: Silica Sand/Furan Binder

Lead time: completed less than 2 weeks

Core box modification cost savings: $5,000

Weight reduction: 2.2 lbs

Amerequip required a conversion of their 11-piece, lasercut welded assembly which in turn, would reduce weight, improve quality, and minimize cost through improved production efficiencies with a one-piece design. Amerequip turned to Neenah Foundry, which created the single ductile iron casting design to be made using a single low-cost core. Neenah used 3D printed cores produced at Hoosier Pattern on an ExOne's S-Max system.

ExOne

Case Study | Morel Industries

Complex digital core cuts lead time, saves thousands

Specifications

Part: Exhaust manifold core

Batch Size: 30

Part Size: 4 x 8 x 28 inch

Material: Gray iron

Traditional Method

Unique wooden pattern for each core. Hand setting to build core assembly.

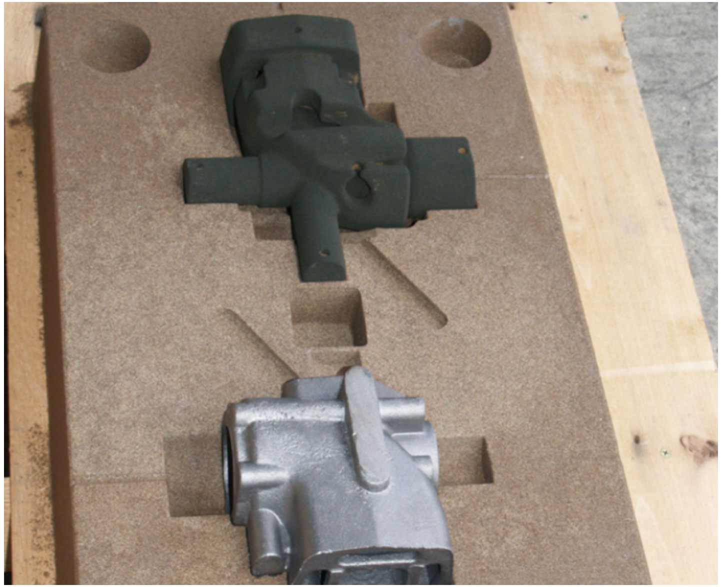
Time: 5 weeks

Cost per Batch: $8,000

ExOne Sand Printing

Method Time: 2 weeks after CAD design

Cost: $1,200



Morel Industries needed a solution to eliminate the human error in the assembly of core boxes used with traditional wood and sand patterns. Working with a local pattern shop with CAD knowledge and expertise, Morel was able to combine 3 cores into 1 printable ExOne core with vents and intricate geometry for their customer. With ExOne's digital printing process, 3 cores were combined into 1, decreasing the scrap rate from 9% to 1%. Lead times were reduced by 60%. Costs were slashed by 85%.

ExOne

CERAMIC 3D PRINTING

Ceramic 3D Printing

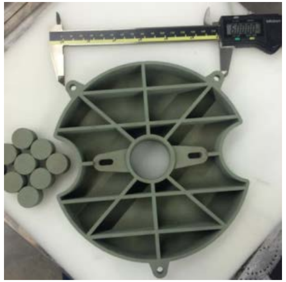
Software being developed to codify and streamline design for binder jetting

- Inherent advantages for ceramics:
  - Print speed, print size, material choices and flexibility

- Application in many ceramic materials markets:
  - Reaction bonded / Siliconized Silicon Carbide (SiC) for optics, automotive, chemical, and high-temperature material industries
  - Tungsten Carbide / Cobalt (WC/Co) for wear parts and cutting tool industries
  - Oxide based ceramics for filters, electronics packaging, etc.
  - Prototyping and low quantity runs of CIM parts

- As binder jetting further develops for ceramics, enhancements for printing small particle size, sinterable ceramic powders will continue to create broader adoption. Published material property characterization data from large industrial players will also drive adoption throughout the industry.

High-density alumina sintering setters printed in 99% purity alumina



SiC optical structure 3D printed preform

3D printed 8” graphite impeller core

NEW OPPORTUNITIES
3D PRINTED TOOLING

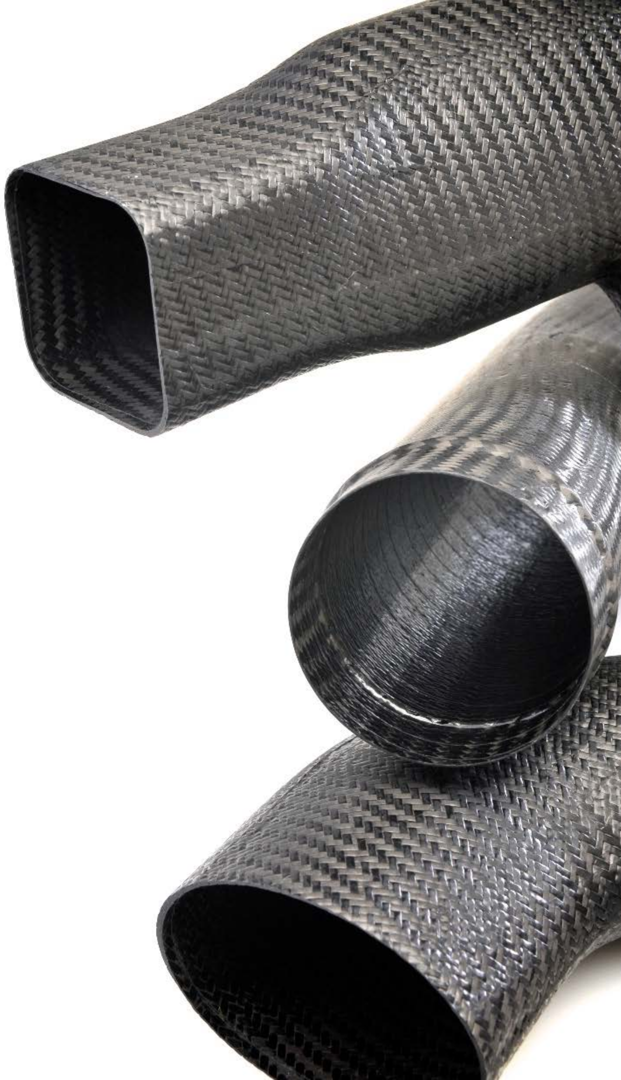
What is Washout Tooling?

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.



ExOne

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.

ExOne

Washout Tooling Industries

Choose a low or high CTE to manage expansion

Aerospace

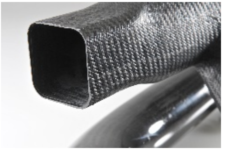
We serve a wide range of customers in this market, including makers of UAVs, with tooling for parts.

- Ducting
- 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



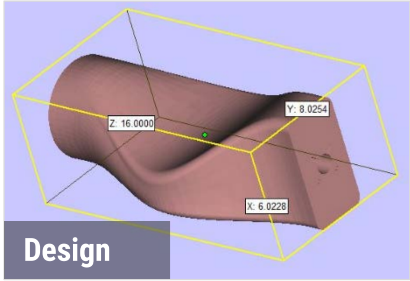
WASHOUT TOOLING PROCESS

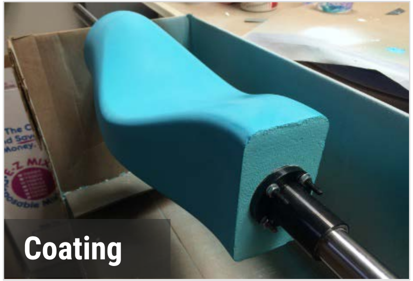
Washout Tooling Process

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

Processes supported by washout tooling include:

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





Washout Tooling Process

Simple Water Washout › Final Part

Remove Tool with Tap Water

Recover and Reuse Sand Media

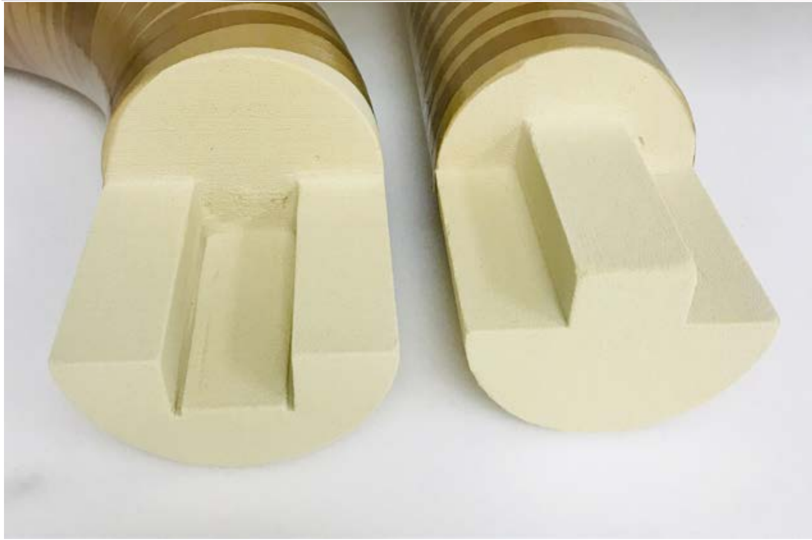
Final Fiberglass Part

ExOne

Extreme Design Benefits

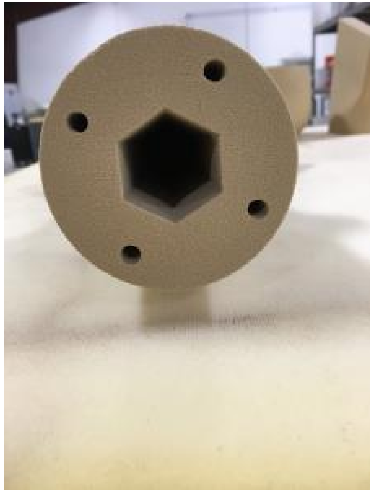
Choose a low or high CTE to manage expansion

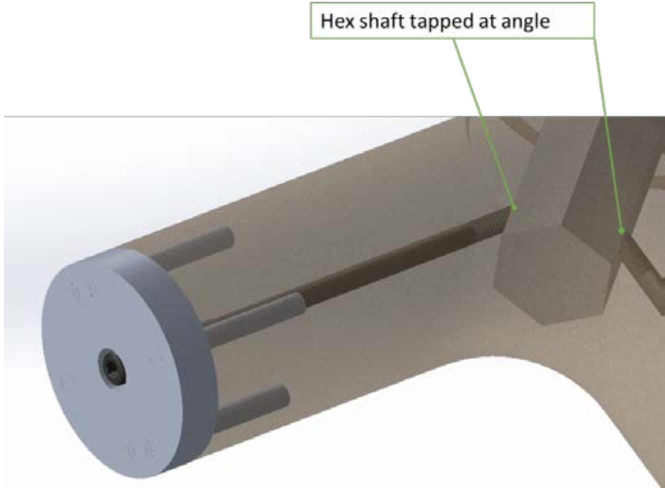
- Novel designs printed in ends of mandrels to create longer mandrels
- Creates ability to manufacturer parts longer than the build volume (L > 800 mm)
- Minimizes shipping issues and potential damage to shipping long mandrels
- A lot of unexplored design possibilities



Integration with Metallic Hardware

Printed Cerabeads washout mandrel (Teflon wrapped) with integrated hardware





Comparing Washout Tooling Methods

High-quality manufacturing in our Saint 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

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)

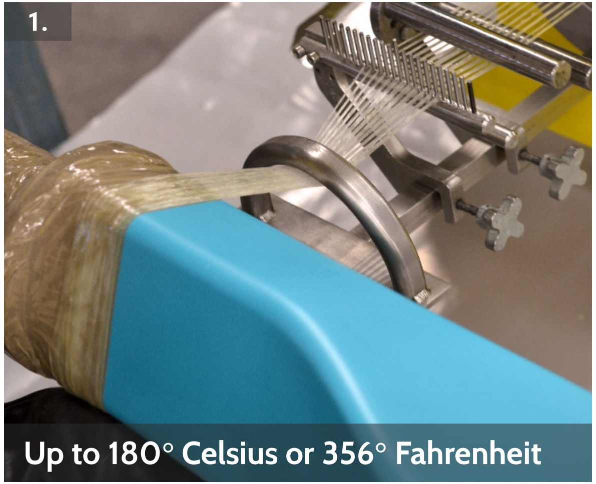
3D Printed Form
Before Coating

ExOne

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.

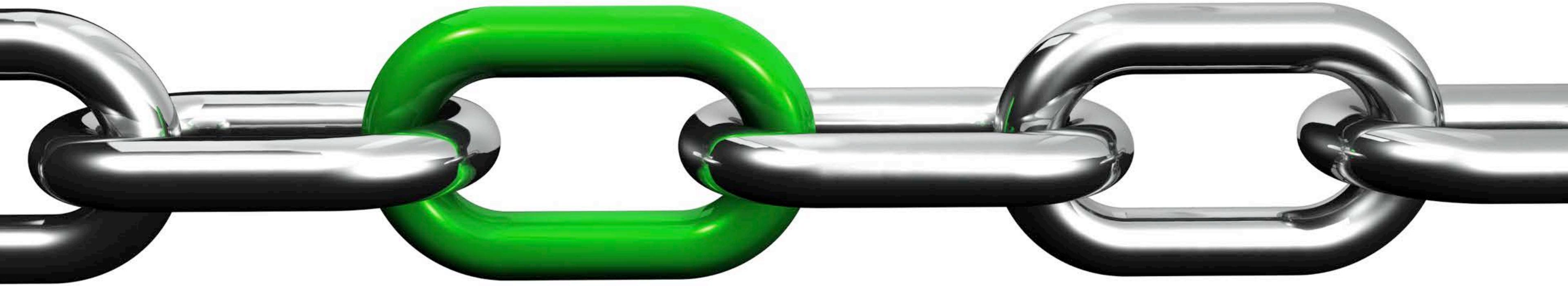


A PROMISING FUTURE
BINDER JET 3D PRINTING

Enabling Smarter, Sustainable Supply Chains

Binder Jet 3D is a serious tool to lightweight and consolidate parts, de-risk supply chains

- Fabricates objects with little to no waste, a dramatic improvement over traditional technologies
- Enables all-new lightweight designs that are not possible or affordable with traditional technologies
- Enables part consolidation that eliminates manufacturing processes and reduces energy consumption
- Eliminates need for hard tooling, enabling distributed manufacturing that shortens supply chains



ExOne

Thank you!

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