EXONE METAL 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
The ExOne Company | Early Years
Highlights of an emerging technology leader

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

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

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.

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

Entry 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.”

1995
1998
2002
2003
2005
### The ExOne Company | A New Era

Highlights of an emerging technology leader

<table>
<thead>
<tr>
<th>Year</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>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.</td>
</tr>
<tr>
<td>2010-2013</td>
<td>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.</td>
</tr>
<tr>
<td>2013</td>
<td>Breakthrough R&amp;D ExOne begins 3D printing full-density single alloy metals without infiltration — a game-changing technology breakthrough.</td>
</tr>
<tr>
<td>2014</td>
<td>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.</td>
</tr>
<tr>
<td>2018</td>
<td>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.</td>
</tr>
<tr>
<td>2019</td>
<td>New Metal Era ExOne launches the Innovent+ and X1 25PRO metal 3D printers for processing ultra-fine MIM metal powders into dense single alloy parts without infiltration.</td>
</tr>
</tbody>
</table>
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

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### ExOne Machine History

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Build Area Dimensions*</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Z Volume</th>
<th>Launch Year</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand, Metal, Ceramic, Composite</td>
<td>4.3 in (125 mm), 3.7 in (95 mm), 3.4 in (85 mm)</td>
<td>0.17 in (4.2 mm), 0.14 in (3.5 mm), 0.12 in (3.0 mm)</td>
<td>3.4 in (85 mm), 2.9 in (73 mm), 2.6 in (67 mm)</td>
<td>3.6 in (91 mm), 3.0 in (76 mm), 2.5 in (63 mm)</td>
<td>2021</td>
<td>Coming Soon</td>
<td></td>
</tr>
<tr>
<td>S-Max Pro®</td>
<td>7.0 in (178 mm), 6.4 in (162 mm), 6.0 in (152 mm)</td>
<td>3.37 in (85 mm), 2.96 in (75 mm), 2.64 in (67 mm)</td>
<td>2.75 in (69 mm), 2.31 in (58 mm), 2.03 in (51 mm)</td>
<td>1.25 cu in (20 cu cm)</td>
<td>2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X1 25Pro®</td>
<td>8.75 in (221 mm), 7.6 in (193 mm), 7.0 in (178 mm)</td>
<td>3.25 in (82 mm), 2.80 in (71 mm), 2.40 in (61 mm)</td>
<td>2.50 in (63 mm), 2.05 in (52 mm), 1.65 in (42 mm)</td>
<td>1.52 cu in (24 cu cm)</td>
<td>2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innov Imp®</td>
<td>6.3 in (160 mm), 5.1 in (130 mm), 4.2 in (107 mm)</td>
<td>2.56 in (65 mm), 2.14 in (54 mm), 1.65 in (42 mm)</td>
<td>2.12 in (54 mm), 1.71 in (43 mm), 1.35 in (34 mm)</td>
<td>0.53 cu in (8.5 cu cm)</td>
<td>2019</td>
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</tr>
<tr>
<td>Exsential®</td>
<td>6.1 in (150 mm), 5.0 in (125 mm), 3.6 in (92 mm)</td>
<td>2.48 in (63 mm), 2.03 in (51 mm), 1.54 in (39 mm)</td>
<td>2.05 in (52 mm), 1.61 in (41 mm), 1.21 in (30 mm)</td>
<td>0.43 cu in (6.9 cu cm)</td>
<td>2019</td>
<td></td>
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</tr>
<tr>
<td>S-Max Silicate</td>
<td>7.0 in (178 mm), 6.4 in (162 mm), 6.0 in (152 mm)</td>
<td>3.37 in (85 mm), 2.96 in (75 mm), 2.64 in (67 mm)</td>
<td>2.75 in (69 mm), 2.31 in (58 mm), 2.03 in (51 mm)</td>
<td>1.16 cu in (19 cu cm)</td>
<td>2014</td>
<td>Discontinued</td>
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<tr>
<td>S-Max Phenolic</td>
<td>7.0 in (178 mm), 6.4 in (162 mm), 6.0 in (152 mm)</td>
<td>3.37 in (85 mm), 2.80 in (71 mm), 2.40 in (61 mm)</td>
<td>2.50 in (63 mm), 2.05 in (52 mm), 1.65 in (42 mm)</td>
<td>0.65 cu in (10.6 cu cm)</td>
<td>2014</td>
<td>Discontinued</td>
<td></td>
</tr>
<tr>
<td>S-Print Silicate</td>
<td>7.0 in (178 mm), 6.4 in (162 mm), 6.0 in (152 mm)</td>
<td>3.37 in (85 mm), 2.80 in (71 mm), 2.40 in (61 mm)</td>
<td>2.50 in (63 mm), 2.05 in (52 mm), 1.65 in (42 mm)</td>
<td>0.74 cu in (12 cu cm)</td>
<td>2014</td>
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<tr>
<td>M-Flex</td>
<td>15.75 in (400 mm), 14.0 in (355 mm), 11.8 in (299 mm)</td>
<td>9.04 in (229 mm), 8.06 in (205 mm), 6.94 in (176 mm)</td>
<td>8.40 in (213 mm), 7.32 in (185 mm), 6.28 in (159 mm)</td>
<td>1.35 cu in (22 cu cm)</td>
<td>2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-Print Phenol</td>
<td>15.75 in (400 mm), 14.0 in (355 mm), 11.8 in (299 mm)</td>
<td>9.04 in (229 mm), 8.06 in (205 mm), 6.94 in (176 mm)</td>
<td>8.40 in (213 mm), 7.32 in (185 mm), 6.28 in (159 mm)</td>
<td>0.76 cu in (12.2 cu cm)</td>
<td>2012</td>
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<tr>
<td>S-Print Furan</td>
<td>15.75 in (400 mm), 14.0 in (355 mm), 11.8 in (299 mm)</td>
<td>9.04 in (229 mm), 8.06 in (205 mm), 6.94 in (176 mm)</td>
<td>8.40 in (213 mm), 7.32 in (185 mm), 6.28 in (159 mm)</td>
<td>0.76 cu in (12.2 cu cm)</td>
<td>2012</td>
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<tr>
<td>S-Max Furan</td>
<td>15.75 in (400 mm), 14.0 in (355 mm), 11.8 in (299 mm)</td>
<td>9.04 in (229 mm), 8.06 in (205 mm), 6.94 in (176 mm)</td>
<td>8.40 in (213 mm), 7.32 in (185 mm), 6.28 in (159 mm)</td>
<td>0.75 cu in (12.1 cu cm)</td>
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<tr>
<td>S-Max Phenolic</td>
<td>15.75 in (400 mm), 14.0 in (355 mm), 11.8 in (299 mm)</td>
<td>9.04 in (229 mm), 8.06 in (205 mm), 6.94 in (176 mm)</td>
<td>8.40 in (213 mm), 7.32 in (185 mm), 6.28 in (159 mm)</td>
<td>0.75 cu in (12.1 cu cm)</td>
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<td>X1-Lab</td>
<td>15 in (381 mm), 15 in (381 mm), 15 in (381 mm)</td>
<td>3.1 in (79 mm), 3.1 in (79 mm), 3.1 in (79 mm)</td>
<td>2.7 in (68 mm), 2.7 in (68 mm), 2.7 in (68 mm)</td>
<td>0.45 cu in (7.3 cu cm)</td>
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<td>R2</td>
<td>7 in (178 mm), 7 in (178 mm), 7 in (178 mm)</td>
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<tr>
<td>S15</td>
<td>59 in (1595 mm), 50 in (1270 mm), 29 in (737 mm)</td>
<td>20 in (510 mm), 17 in (432 mm), 10 in (254 mm)</td>
<td>17 in (432 mm), 14 in (356 mm), 7 in (177 mm)</td>
<td>0.49 cu in (8.0 cu cm)</td>
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<td>R10</td>
<td>36 in (915 mm), 18 in (457 mm), 12 in (305 mm)</td>
<td>15 in (381 mm), 7 in (178 mm), 3 in (76 mm)</td>
<td>12 in (305 mm), 6 in (152 mm), 2 in (51 mm)</td>
<td>0.37 cu in (6.1 cu cm)</td>
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<tr>
<td>RTS-300</td>
<td>10.6 in (270 mm), 10.6 in (270 mm), 10.6 in (270 mm)</td>
<td>8.8 in (223 mm), 8.8 in (223 mm), 8.8 in (223 mm)</td>
<td>7.1 in (180 mm), 7.1 in (180 mm), 7.1 in (180 mm)</td>
<td>1.36 cu in (22 cu cm)</td>
<td>1998</td>
<td>Discontinued</td>
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*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

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<thead>
<tr>
<th>Country</th>
<th>Metal</th>
<th>Sand</th>
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<td>United States</td>
<td>90</td>
<td>29</td>
</tr>
<tr>
<td>Canada</td>
<td>7</td>
<td>2</td>
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<tr>
<td>Mexico</td>
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**AMERICA**

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<tr>
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<td>32</td>
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<tr>
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<tr>
<td>India</td>
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<td>Saudi Arabia</td>
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<td>Singapore</td>
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<td>South Korea</td>
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<td>Thailand</td>
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**ASIA**

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<td>France</td>
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<td>Turkey</td>
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**EUROPE**

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<tr>
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<td>France</td>
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<td>Turkey</td>
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<td>11</td>
</tr>
<tr>
<td>Poland</td>
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</table>

167 Sand
312 * MACHINES WORLDWIDE
145 Metal

* sold machines as of Q2 2020
ExOne | Our Collaboration Partners

Critical research and development network

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

Amy Elliott, PhD Research Scientist, Oak Ridge National Laboratory ORNL
OUR CORE TECHNOLOGY
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.**

**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.
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

 Binder Jetting Technology
 Metal Fused Deposition Modeling
 Directed Energy Deposition
 Electron Beam Powder Bed Fusion
 Laser-based Powder Bed Fusion

AM Power Forecast

<table>
<thead>
<tr>
<th>Year</th>
<th>Binder Jetting</th>
<th>Metal Fused Deposition</th>
<th>Directed Energy</th>
<th>Electron Beam</th>
<th>Laser-based</th>
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<tbody>
<tr>
<td>2018</td>
<td>78%</td>
<td>9%</td>
<td>3%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>2023</td>
<td>57%</td>
<td>31%</td>
<td>5%</td>
<td>4%</td>
<td>3%</td>
</tr>
</tbody>
</table>
Liquid binder is applied to a layer of powder to form high-value parts and tooling.

**Binder Jetting | 3D Printing Process Overview**

**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
- 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.
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.
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 | Binder Jetting Materials

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

ExOne Binder Jet 3D Printing Materials

<table>
<thead>
<tr>
<th>3D Printers</th>
<th>sands</th>
<th>ceramics</th>
<th>composites</th>
<th>100% metals</th>
<th>build volume</th>
<th>applications</th>
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<tbody>
<tr>
<td>X1 160Pro</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>XL</td>
<td>• Serial Production&lt;br&gt; • Low or High Volumes&lt;br&gt; • MIM-Like Parts&lt;br&gt; • Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
<tr>
<td>X1 25Pro</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>L</td>
<td>• Metalcasting&lt;br&gt; • Molds &amp; Cores&lt;br&gt; • Sustainable Tooling&lt;br&gt; • Production&lt;br&gt; • Low or High Volumes&lt;br&gt; • Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
<tr>
<td>Innovent+ or Pro</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>S/M</td>
<td>• Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
<tr>
<td>M-Flex</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>L</td>
<td>• Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
<tr>
<td>S-Print</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>XL</td>
<td>• Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
<tr>
<td>S-Max</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>XXL</td>
<td>• Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
<tr>
<td>S-Max Pro</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>XXL</td>
<td>• Prototypes&lt;br&gt; • R&amp;D</td>
</tr>
</tbody>
</table>

Plus, another 25 R&D materials – including aluminum and more
Binder Jetting | Print, Pour and Produce
A flexible array of materials for direct printing complex, high-value parts and tooling
Binder Jetting delivers complex, high-value parts faster, with a dramatic reduction in waste.

**Binder Jetting | Four Primary Application Categories**

**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.
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

- **DESIGN FREEDOM**
  - 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

- **SAVINGS**
  - 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

- **WASTE REDUCTION**
  - Reduce or eliminates a wide range of wastes
    - Material waste
    - Hard tooling
    - Excess mfg processes
    - Inventory
    - Labor
    - (reduce or eliminate excess assembly)
  - Saves costs by streamlining many forms of wastes
    - Waiting
    - Defects
    - Over-processing
    - Overproduction (no min. volumes)
    - Transportation and storage of parts to assemble

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ExOne | Eliminating Costly Waste

3D printing eliminates wasted time and resources, improving profitability.

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

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

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

Lean production is focused on reducing and eliminating waste.
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
BINDER JETTING CONSIDERATIONS
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

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
### Metal 3D Printing | Applications by Porosity

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

#### Product Forms

<table>
<thead>
<tr>
<th>Coarse Powders</th>
<th>Fine Powders</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials (D&lt;sub&gt;50&lt;/sub&gt; &gt;20µ):</strong></td>
<td><strong>Materials (D&lt;sub&gt;50&lt;/sub&gt; &lt;20µ):</strong></td>
</tr>
<tr>
<td>Minerals, Ceramic,</td>
<td>Minerals, Ceramic,</td>
</tr>
<tr>
<td>Carbon, Glass, Ceramic,</td>
<td>Glass, MIM, CIM powders</td>
</tr>
<tr>
<td>Metal</td>
<td>Powders</td>
</tr>
</tbody>
</table>

#### Markets:

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

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

#### Materials (D<sub>50</sub> >20µ):

- Bonded
- Partially Sintered
- Infiltrated
- Highly Sintered (Coarse)

#### Materials (D<sub>50</sub> <20µ):

- Bonded
- Partially Sintered
- Infiltrated
- Highly Sintered

© 2020 The ExOne Company
Many binders are proprietary to manufacturers and play a critical role in Binder Jetting processes. Here are some considerations:

**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 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 RHEOLOGY**
- Viscosity
- Surface Tension
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**
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
METAL 3D PRINTING
Transitioning from first serial applications to industrial use

- Started with larger particle sizes and porous/infiltrated parts
- Growth has occurred as densities have increased and manufacturers take advantage of BJT for problem-solving
- Today final part density is now more than 97% dense, in line with MIM and better than investment castings
  - Maturity for production coming fast as software solutions enable BJT design and sintering support

**INTRODUCTION**

Late 1990s
- First Metal Binder Jet System (RTS-300)
- Porous metal applications (filters, consumer goods)
- Iterative Process Optimization

**GROWTH**

2013-2020
- High Density Applications
- First Serial Production Applications
- Plug-and-Play Systems
- Software Design & Sinter Support
- Competition

**MATURITY**

Production
- First applications underway

**DECLINE**
Metal 3D Printing | ExOne Leadership

We are the market share leader in binder jet 3D printers for metals and ceramics

Binder Jet 3D Printers
- Innovaent+, a reliable entry-level model
- M-Flex, an affordable, large and reliable model
- X1 25Pro, a cutting-edge large production system
- X1 160Pro, our largest and smartest production system

APPLICATIONS
- Direct 3D printing of metal parts in a variety of alloys
- Direct 3D printing of ceramics
- Direct 3D printing of composites

SUPPORT SERVICES
- Comprehensive implementation and training
- 3D printed parts on demand
- Design for Additive Manufacturing (DfAM) services
- Custom development for special manufacturing programs, including custom metal development

DIRECT METAL 3D PRINTING
DIRECT CERAMIC 3D PRINTING

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

3D printing greatly simplifies production of difficult to produce ceramic materials, such as silicon carbide.
Metal 3D Printing | Transformational Benefits
Faster delivery times and new design freedoms

Quick delivery of accurate and dense metal parts. Process and material waste efficiencies over traditional methods. New design and lightweighting opportunities.

- **SPEED**
  - Fast Delivery Times
  - Print a wide variety of metal powders on the same machine

- **FLEXIBILITY**
  - Consolidate parts, process steps and save on material costs

- **WASTE REDUCTION**
  - Improve designs without a cost penalty

- **RAPID DESIGN CHANGES**
  - Consolidate parts, reduce weight, deliver all-new designs without traditional limitations

- **EXCEPTIONAL DESIGN FREEDOM**
The 3D printing technology that is best suited for mass production

Currently, we can binder jet to 1-3% dimensional tolerance on a first effort. Improving to below 1% requires about 3 iterations of printing and sintering. However, the benefits can be quite meaningful as unit volume increases.

“Binder jetting exhibits lower capital and operating costs when compared to similar direct metal technologies. The fast manufacturing speeds make binder jetting a scalable process and well suited for mass production. For these reasons, binder jetting is the best possible future investment for a mass production setting.”

Philip Morton, Manager
W.M. Keck Center for 3D Innovation
The University of Texas at El Paso

The “No-Scale” Effect of Binder Jetting

Cost (USD) Millions

Number of parts

0 100 200 300 400

EBM
SLM
Binder Jetting

PROTOTYPING PRODUCTION
BATCH PRODUCTION VOLUME TOOLING
Metal 3D Printing | Successful Sintering
Predictable process with uniform densities. Sintering exposes microscopic quality of the print.

Green density target: 50–60% for most metals
• High green density = less shrinkage
• High green density = less distortion
• High green density = tight tolerances

Sintering time, temperatures (often in excess of 2000° F) and conditions must be tailored to the precise part to achieve target part density.

Sintering Considerations
► Quality 3d Print In > Quality Sinter Out
► Shrinkage
► Gravity
► Setters
► High-quality heat profiles
► Final metallurgy

Water Atomized and Gas Atomized 316L

<table>
<thead>
<tr>
<th>Powder</th>
<th>D&lt;sub&gt;10&lt;/sub&gt; D&lt;sub&gt;50&lt;/sub&gt; D&lt;sub&gt;90&lt;/sub&gt; (µm)</th>
<th>Apparent, Tap Density</th>
<th>Green Density , Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA 316L</td>
<td>2.5, 6.2, 12.9</td>
<td>37%, 53.7%</td>
<td>54.1%, 0.65%</td>
</tr>
<tr>
<td>GA 316L</td>
<td>3.6, 8.3, 15.6</td>
<td>42%, 56.9%</td>
<td>55.6%, 0.58%</td>
</tr>
</tbody>
</table>

• Green densities are high and variabilities are low
• Triple ACT delivers sintered density of 98-99%.
Delivering high-density green parts is essential for high-quality results

Exclusive, patented system for dispensing, spreading and compacting the finest powders for high green strength

- Delivering Fast, High-Quality Parts
- Patented ultrasonic dispensing system of the finest powders.
- Patented spreading roller system
- Counter-rolling spreader and compactor
- Works in conjunction with patented compacting roller featuring unique design
- Complete system works together to deliver green-part density standard deviation of <1% at print speeds of over 150 mm/sec
- Adjustable roller spacing provides controlled densities that approach or exceed tap densities

Delivers industry-leading part density and repeatability
Learn More: www.exone.com/tripleact
Metal 3D Printing | High Density, Superior 3D Microstructures

Why? Binder jetting 3D prints parts without particle fusion until final sintering

- Equiaxed grain structure for binder jetting leads to isotropic material properties (30 to 60µm grain size)
- Tiered, columnar grain structure for EBM and DMLS (80 to 400µm grain size)
- Minimal chemical segregation at grain boundary in binder jetting parts due to room temperature processing
- Binder jetting microstructure closely resembles microstructure for standard PM parts
Metal 3D Printing | Material Flexibility & Qualification

3D print more than twenty metal, ceramic and composites – plus R&D

R&D QUALIFIED: Have passed a preliminary qualification phase by ExOne and are deemed printable, supported by ongoing development.

CUSTOMER-QUALIFIED: Qualified by customers with their own standards and being successfully 3D printed for their own applications.

THIRD-PARTY QUALIFIED: Have passed rigorous tests over multiple builds and have verified material property data from an independent third party. General marketplace readiness.
Metal 3D Printing | Rethink What’s Possible
Dense and strong single alloys parts with complex geometries

Binder jetting makes impossible parts possible. It also makes them faster with less waste.

Print and sinter true round holes
Print extremely fine, strong features

Automotive Sensor Bracket 3D Printed in 316L

Altair bike pivot in 316L
Binder Jetting | Metal Design Guidelines
Part size, wall thickness, minimum feature size, and aspect ratio

- Scaling up for most metals:
  - 19% in X and Y
  - 21% in Z
- Shrinkage of green part is typically 16%
- Iterative process for dimensional tolerances
  - +/- 1-3% on first print and sinter
  - Usually 3-4 iterations for <1%
- Minimum wall thicknesses varies with geometry and part size. Generally:

<table>
<thead>
<tr>
<th>Part Size</th>
<th>Min. Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-75 mm (0.12-3 in)</td>
<td>1 mm (0.04 in)</td>
</tr>
<tr>
<td>75-150 mm (3-6 in)</td>
<td>1.5 mm (0.06 in)</td>
</tr>
<tr>
<td>150-200 mm (6-8 in)</td>
<td>2 mm (0.08 in)</td>
</tr>
<tr>
<td>200-300 mm (8-12 in)</td>
<td>3 mm (0.13 in)</td>
</tr>
</tbody>
</table>

- Inside corners and sharp intersections should have a filleted edge, with the fillet radius approximately equal to the connecting wall thickness
- Consistent cross sections recommended
- Cavities require drain holes and should be placed centrally to each pocket for depowdering
- For “dumbbell” designs with a thin connection between thick walls or masses, maintain consistent wall thickness as much as possible
- Aspect ratio recommendation: 15-20:1
METAL 3D PRINTERS
Metal 3D Printing | Product Overview
Binder jetting for metals, ceramics and composite powders.

- **Innovent+**
  - Research
  - Prototyping
  - Rapid product development
  - Short-run production

- **M-Flex**
  - Research
  - Prototyping
  - Rapid product development
  - Short-run production

- **X1 25Pro**
  - Research
  - Prototyping
  - Rapid product development
  - Short-run production
  - Continuous 24/7 production
  - Serial production

- **X1 160Pro**
  - Research
  - Prototyping
  - Rapid product development
  - Short-run production
  - Continuous 24/7 production
  - Serial production

**MAIN SPECIFICATIONS**

- **Innovent+**
  - Build envelope: 160 x 65 x 65 mm (6.3 x 2.5 x 2.5 in)
  - Volume: 676 cc
  - Max throughput: 166 cc/h
  - Min layer height: 30-200 μm
  - Min powder size: 2 μm (d50)

- **M-Flex**
  - Build envelope: 400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)
  - Volume: 25L
  - Max throughput: 1,600 cc/h
  - Min layer height 50-200 μm
  - Min powder size: 15 μm (d50)

- **X1 25Pro**
  - Build envelope: 400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)
  - Volume: 25L
  - Max throughput: 3,600 cc/h
  - Min layer height: 30-200 μm
  - Min powder size: 5 μm (d50)

- **X1 160Pro**
  - Build envelope: 800 x 500 x 400 mm (31.5 x 19.7 x 15.8 in)
  - Volume: 160L
  - Est. throughput: 10,000+ cm³/hour
  - Est. layer height: 30-200 μm
  - Est. Min powder size: 5 μm (d50)

*An affordable, compact and reliable 3D printer for metal, ceramic or composite. Since 2018.*

*An affordable, large and reliable 3D printer for metal, ceramic or composite powders. Since 2013.*

*A large, smart 3D printer for high-quality serial production of metal, ceramic or composite parts. 2019.*

*The largest and most advanced 3D printer for production of metal, ceramic or composite parts. 2020.*

Specifications are subject to change without notice. Some data may depend on the size and characteristics of the powder being processed.
ExOne | Innovent+®

An affordable, compact and reliable 3D printer for metal, ceramic or composite. Since 2018.

- Research
- Prototyping
- Rapid product development
- Short-run production

**DETAILS**

- Build envelope: 160 x 65 x 65 mm (6.3 x 2.5 x 2.5 in)
- Volume: 676 cc
- Max throughput: 166 cc/h
- Min layer height: 30-200 μm
- Min powder size: 2 μm (d50)
- Binder systems: AquaFuse™, CleanFuse™, FluidFuse™, PhenolFuse™
- Process options enabled by various printhead sizes, including: 80, 30, or 10 picoliter printhead
- Print resolution: >30 μm voxels
- Operator interface: Full HD multi-touch display, On-board Wi-fi, USB input
  Software: Model review, rescaling technology, check customizable, print parameters
- Improved print speed control

Specifications are subject to change without notice. Some data may depend on the size and characteristics of the powder being processed.
An affordable, large and reliable 3D printer for metal, ceramic or composite powders. Since 2013.

- Research
- Prototyping
- Rapid product development
- Short-run production

User-friendly touchscreen control

Easy access cabinet

**Details**

- **Build envelope:** 400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)
- **Volume:** 25L
- **Max throughput:** 1,600 cc/h
- **Min layer height:** 50-200 μm
- **Min powder size:** 15 μm (d50)
- **Print resolution:** >50 μm voxels
- **Binder systems:** AquaFuse™, CleanFuse™, FluidFuse™, PhenolFuse™
- **3D prints** metal, ceramic, sand, and composite powders

*Specifications are subject to change without notice. Some data may depend on the size and characteristics of the powder being processed.*
ExOne | X1 25Pro®

A large, smart 3D printer for high-quality serial production of metal, ceramic or composite parts. Since 2019.

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

Details:
- Build envelope: 400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)
- Volume: 25L
- Max throughput: 3,600 cc/h
- Min layer height: 30-200 μm
- Min powder size: 5 μm (d50)
- Printhead options: 10, 30 or 80 picoliter printhead
- Print resolution: >30 μm voxels
- Binder systems: AquaFuse™, CleanFuse™, FluidFuse™, PhenolFuse™
- 3D prints metal, ceramic, sand, and composite powders

Specifications are subject to change without notice. Some data may depend on the size and characteristics of the powder being processed.
ExOne | X1 160Pro™

The largest and most advanced 3D printer for production of metal, ceramic or composite parts. 2020.

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

New conveyor system for continuous, serial production

DETAILS
- Build envelope: 800 x 500 x 400 mm (31.5 x 19.7 x 15.8 in)
- Volume: 160L
- Est. throughput: 10,000+ cm³/hour
- Est. layer height: 30-200 μm
- Est. Min powder size: 5 μm (d50)
- Printhead options: 10 picoliter printhead
- Print resolution: >30 μm voxels
- Binder systems: AquaFuse™, CleanFuse™, FluidFuse™, PhenolFuse™
- 3D prints metal, ceramic, sand, and composite powders
- Siemens MindSphere optional

Specifications are subject to change without notice. Some data may depend on the size and characteristics of the powder being processed.
The InnoventPro

A vision for the future

ENTRY-LEVEL BINDER JETTING JUST GOT BETTER

We’ve taken the world’s best-selling metal binder jetting system, the Innovent, and reimagined our entry-level system to deliver an even bigger bang that takes your work further than ever. The new InnoventPro, offered in 3L and 5L options, combines the ease of use of the Innovent+ with the robust X1 25Pro production capabilities, using the same piezoelectric printhead modules across the lineup.

The Innovent Pro delivers 3X the build area, faster throughput, and even more reliability from the most trusted name in metal binder jetting, ExOne. Suitable for R&D, prototyping and precision manufacturing, the Innovent Pro features ExOne’s industry-leading Triple ACT. This patented advanced compaction technology quickly transforms more than 20 metal and ceramic powders into high-density parts (>97%) with industry-leading dimensional tolerance (<1+/-2.5%), with final results dependent on material selection.

A complement to any metal injection molding or shop-floor operation, the ExOne Innovent Pro allows manufacturers to affordably offer low- or mid-volume production runs. For our faithful R&D customers, the Innovent Pro will continue to offer easy material changeover.

Even better, when your project is ready for high-volume production, you can simply scale up to one of ExOne’s larger binder jet systems, the X1 25Pro or X1 160Pro, minimizing or eliminating the re-engineering often needed to take a prototype to full production.
InnoventPro 3L and 5L

Preliminary machine specifications, subject to change

- 3L build box: 125 x 220 x 100 mm (2.75L)
- 5L build box: 125 x 220 x 200 mm (5.5 L)
- Triple ACT recoating system
  - <1% green part-to-part uniformity
- Same exact printhead as used in the X1 25Pro
- Both use same printhead modules as 160Pro
- Print speeds will be at least 700 cc/hour
- Standard MIM powders (Min. Powder Size: 5 \( \mu m \) (d50))
- Improved powder management and handling
  - Near net zero emissions
  - Easy to clean, change out powders
- Serial build boxes with covers
- In-situ process monitoring
  - Temperature, humidity, camera, internals
- Siemens controllers and MindSphere with ExOne Scout App
- NOTE: 3L size is maximum to still carry a box full of metal powder under most US guidelines without assistive device

The InnoventPro will combine the ease of use and low cost of the Innovent+ with the production capabilities of the X1 25Pro. The InnoventPro will be capable of producing parts up to 100x180x80 mm (3L) or 100x180x80 mm (5L) using MIM-sized powders in a variety of alloys.
InnoventPro Ideal for R&D, Smaller Part Production

Your path to scale up to high-volume serial production for full range of part sizes
Preliminary InnoventPro Timeline

A plan for the future

- **FORMNEXT ‘21**
  - 3L PRODUCTION LAUNCH

- **InnoventPro 3L AVAILABILITY**
  - Limited: Q4 2021
  - Volume: Q1/2 2022

- **RAPID ‘22**
  - 5L PRODUCTION LAUNCH

- **InnoventPro 5L AVAILABILITY:**
  - Q2/3 2022
METAL MATERIALS AND BINDERS
Metal 3D Printing | Material Qualification Process
ExOne systems print more than two dozen metal, ceramic and composite powders

- **R&D Qualified**
  - Verifies printability
  - Powder characterization
  - Powder conditioning
  - Sieve test
  - Print trials
  - Sintering trials
  - Material Testing - Mechanical, Microscopy & Chemistry
  - 24+ Materials

- **Customer-Qualified**
  - These materials are routinely being 3D printed by ExOne customers prior to readiness qualification for the broad marketplace.
  - 14 Materials

- **Third-Party Qualified**
  - Uniformity testing
  - Test powder rheology & PSD after multiple builds
  - Print and sinter multiple builds
  - Full third-party qualification
  - 8 Materials

ExOne's tiered, multistep qualification process to ensure materials will deliver consistent, high-quality results – from the 3D printing process through final sintering

- **Full Third-Party Qualification**
  - Tensile X, Y, Z
  - Poisson Ratio
  - Hardness
  - Impact
  - Surface Roughness
  - Chemistry
  - Machinability (Option)
  - Weldability (Option)
  - Thermal Conductivity (Option)
  - Specific Heat (Option)
  - Corrosion (Option)
  - All tested against MPIF standards
Third-Party Qualified Materials

Have passed rigorous ExOne tests over multiple builds and have verified material property data from an independent third party. General marketplace readiness.

Single Alloy Metals
1. 17-4PH SS
2. 304L SS
3. 316L SS
4. M2 Tool Steel
5. Inconel 718

Metal Composites
1. 316 SS i/w Bronze
2. 420 SS i/w Bronze
3. Tungsten i/w Bronze
Customer-Qualified Materials
Have been qualified by ExOne customers with their own standards and are being successfully printed for their own applications.

<table>
<thead>
<tr>
<th>Single Alloy Metals</th>
<th>Ceramics</th>
<th>Ceramic-Metal Composites</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 17-4PH SS*</td>
<td>1. Alumina</td>
<td>1. Boron Carbide i/w Aluminum</td>
</tr>
<tr>
<td>2. 304L SS*</td>
<td>2. Carbon</td>
<td>2. Silicon Carbide w/Silicon</td>
</tr>
<tr>
<td>3. 316L SS*</td>
<td>3. Natural Sands</td>
<td></td>
</tr>
<tr>
<td>4. Cobalt Chrome</td>
<td>4. Synthetic Sands</td>
<td></td>
</tr>
<tr>
<td>5. Copper</td>
<td>5. Silicon Carbide</td>
<td></td>
</tr>
<tr>
<td>7. Inconel 625</td>
<td></td>
<td>Metal Composites</td>
</tr>
<tr>
<td>8. Titanium</td>
<td></td>
<td>1. 316 SS i/w Bronze*</td>
</tr>
<tr>
<td>9. Tungsten Heavy Alloy</td>
<td></td>
<td>2. 420 SS i/w Bronze*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Tungsten w/w Bronze*</td>
</tr>
</tbody>
</table>

*This material is also a third-party qualified material
R&D Materials
Have passed a preliminary qualification phase by ExOne and are deemed printable, supported by ongoing development.

<table>
<thead>
<tr>
<th>Single Alloy Metals</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 17-4PH SS**</td>
<td>19. M2 Tool Steel**</td>
<td></td>
</tr>
<tr>
<td>2. 304L SS**</td>
<td>20. Panacea</td>
<td></td>
</tr>
<tr>
<td>3. 316L SS**</td>
<td>21. Titanium**</td>
<td></td>
</tr>
<tr>
<td>4. 4140</td>
<td>22. Tungsten (bonded or green)</td>
<td></td>
</tr>
<tr>
<td>5. 420</td>
<td>23. Tungsten Heavy Alloy**</td>
<td></td>
</tr>
<tr>
<td>6. 4340</td>
<td>24. TZM Molybdenum</td>
<td></td>
</tr>
<tr>
<td>7. 4605</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Bronze</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Cobalt Chrome**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Copper*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. H11 Tool Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. H13 Tool Steel**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Hastelloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Haynes 230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Inconel 625**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Inconel 718</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Iron-Chrome-Aluminum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ceramic-Metal Composites</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Boron Carbide i/w Aluminum**</td>
<td></td>
</tr>
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<td>2. Silicon Carbide w/Silicon**</td>
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</tbody>
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<tr>
<th>Metal Composites</th>
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</thead>
<tbody>
<tr>
<td>1. 316 SS i/w Bronze**</td>
<td></td>
</tr>
<tr>
<td>2. 420 SS i/w Bronze**</td>
<td></td>
</tr>
<tr>
<td>3. Iron i/w Bronze</td>
<td></td>
</tr>
<tr>
<td>4. Tungsten i/w Bronze**</td>
<td></td>
</tr>
<tr>
<td>5. Tungsten i/w Copper</td>
<td></td>
</tr>
<tr>
<td>6. Tungsten i/w Invar</td>
<td></td>
</tr>
</tbody>
</table>
Metal 3D Printing | ExOne Fuse™ Binders

Our growing portfolio of innovative metal binders

One of the reasons ExOne metal binder jet systems can print such a diversity of powdered materials is our portfolio of specialty Fuse™ binders, which deliver unique benefits for the material being 3D printed.

CleanFuse™
A premium, clean-burning binder that leaves behind no carbon residue and works well with metallic materials negatively affected by carbon

FluidFuse™
A versatile solvent-based binder with low viscosity that works well with a variety of metallic and non-metallic materials, including ceramics

AquaFuse™
A water-based binder that works well with a variety of metallic material

PhenolFuse™
A phenolic binder best suited for printing high-temperature materials, including non-metals such as carbon, tungsten carbide (WC), silicon carbide (SiC), and other ceramics

COMING SOON: NanoFuse™
A new line of groundbreaking binders featuring suspended nanoparticles to improve the quality of binder jetting results with certain materials, such as copper and aluminum

BINDER CONSIDERATIONS
- Viscosity
- Saturation
- Bleeding X/Y
- Debinding
METAL 3D PRINTING SERVICES
ExOne | Metal 3D Printing Solutions

Full support for sand casting with 3D printing technology

The ExOne Metal3D Team has world-class knowledge of metal AM designs and processes for binder jetting.

ExOne Metal 3D Services

- Printed Metal Parts on Demand
- Design and Engineering Service
  - Requirements assessment
  - Experienced 3D design services
  - Final part printing and finishing
  - Custom material development
  - Part qualification services
  - Full Inspection Services
- Training
  - Full implementation and design training

360° SUPPORT
- Manufacturers
- Machine Shops
- Researchers
- Educators
- Designers

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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.
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.
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.
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
Choose a low or high CTE to manage expansion

- Novel designs printed in ends of mandrels to create longer mandrels
- Creates ability to manufacture 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

<table>
<thead>
<tr>
<th>Technology</th>
<th>NRE Cost</th>
<th>Build Cost</th>
<th>Build Time</th>
<th>Tooling Req’d</th>
<th>Use Temp</th>
<th>Removal</th>
<th>CTE</th>
<th>Use Driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Jetting</td>
<td>$</td>
<td>$</td>
<td>Low</td>
<td>No</td>
<td>180° C</td>
<td>Tap water</td>
<td>Low or High</td>
<td>New technology</td>
</tr>
<tr>
<td>FDM (SSYS)</td>
<td>$</td>
<td>$$</td>
<td>Med</td>
<td>No</td>
<td>180° C</td>
<td>Hot solvent</td>
<td>High</td>
<td>New technology</td>
</tr>
<tr>
<td>Plaster / Castable Media</td>
<td>$$</td>
<td>$</td>
<td>Low*</td>
<td>Yes</td>
<td>120° C</td>
<td>Breakout</td>
<td>Med</td>
<td>High Quantity, Legacy, inexpensive</td>
</tr>
<tr>
<td>Bladder Molding</td>
<td>$$$</td>
<td>$$$</td>
<td>High</td>
<td>Yes</td>
<td>&gt;180° C</td>
<td>Deflate</td>
<td>High</td>
<td>High quantity, OML &amp; IML control</td>
</tr>
<tr>
<td>Breakdown Tooling</td>
<td>$$$</td>
<td>$$$</td>
<td>High</td>
<td>Yes</td>
<td>&gt;180° C</td>
<td>Multi-pc</td>
<td>High</td>
<td>High quantity</td>
</tr>
</tbody>
</table>
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.
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
Thank you!

The ExOne Company
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