BINDER JET TOOLING FOR METAL PARTS

Team ExOne

Oct. 27, 2021

END-USE METAL PARTS TOOLING

ExOne Binder Jetting for Final Metal Parts

Several options to produce tooling and tools for metal production

Sandcasting molds and cores for casting wide range of metals

- ExOne is No. 1 global market leader in this area
- While this is a mature area, still tremendous opportunity to tap new designs and other benefits
- Unique mold and core designs that can deliver done-in-one castings

Directly Print Tooling X1 MetalTool

- Directly 3D print metal tools for durable use in production of metal parts
- End-of-arm tooling
- Consumable cutting tools
- Stamping tools >>

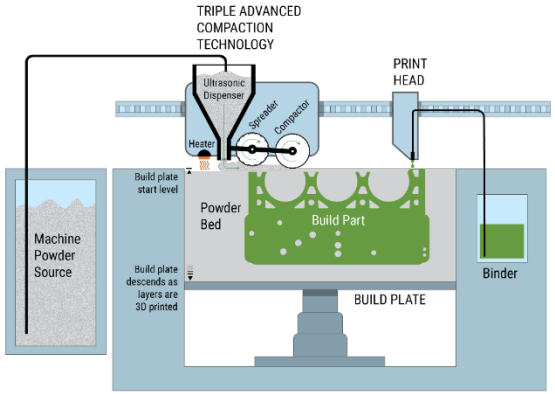
X1 DieMold

- In development with key Original Equipment Manufacturers
- Available Future Materials: H11, H13, 4140

X1 MetalTool 420i used for stamping aluminum

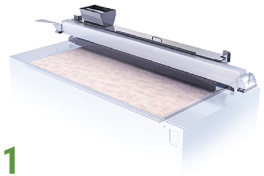
Binder Jetting | Process Overview

Liquid binder applied to powder to form parts and tooling

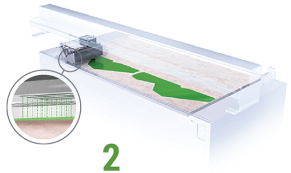


Digital File Prep → Machine & Material Prep

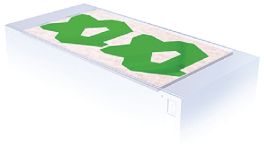
3D Printing



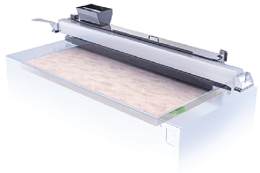
1 Powder is deposited.



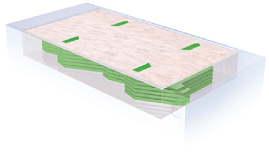
2 Inkjet applies binder.



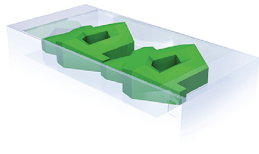
3 Each layer is printed fast.



4 Powder is recoated.



5 The process repeats.



6 3D printing is complete.

Next steps depend on application and specific materials →

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

ITERATIVE PROCESS WITH BIG PAYOFFS

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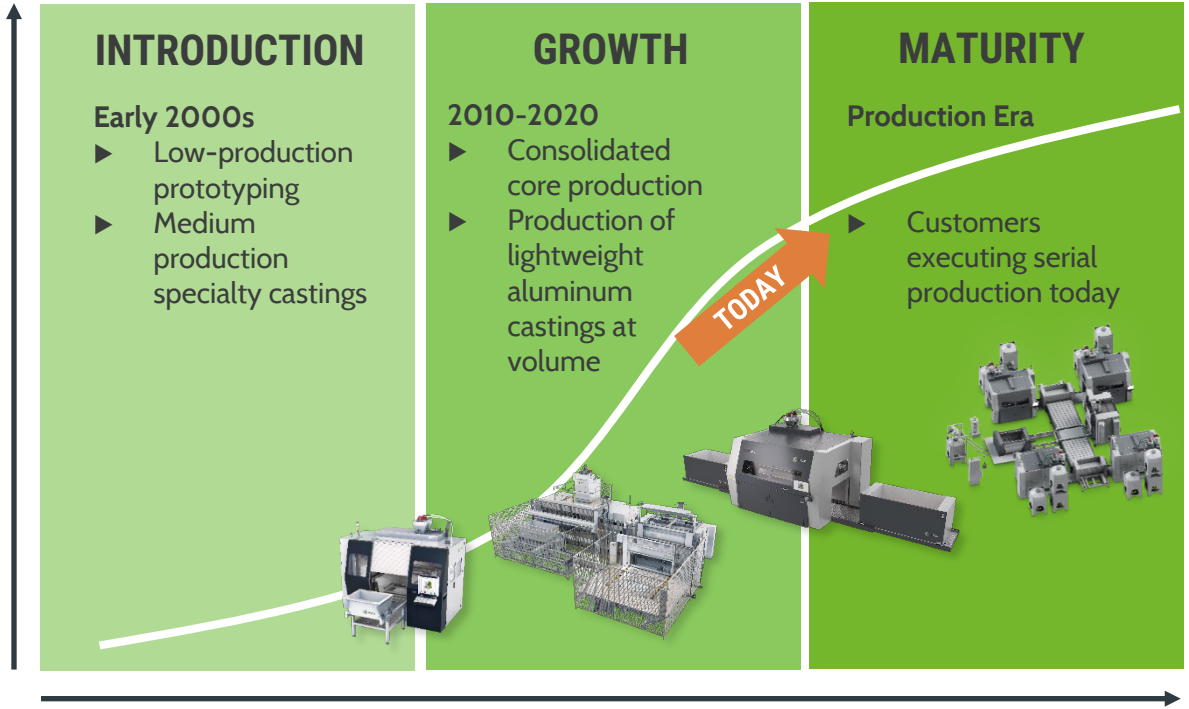
Sand 3D Printing | History

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 binder for low-emission, aluminum-friendly casting



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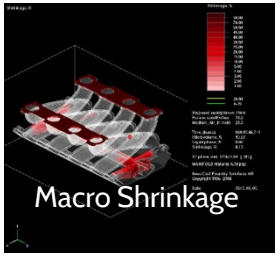
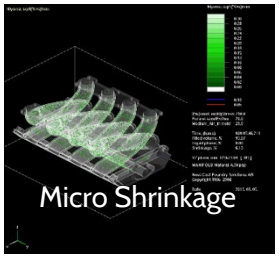
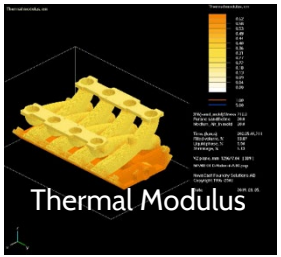
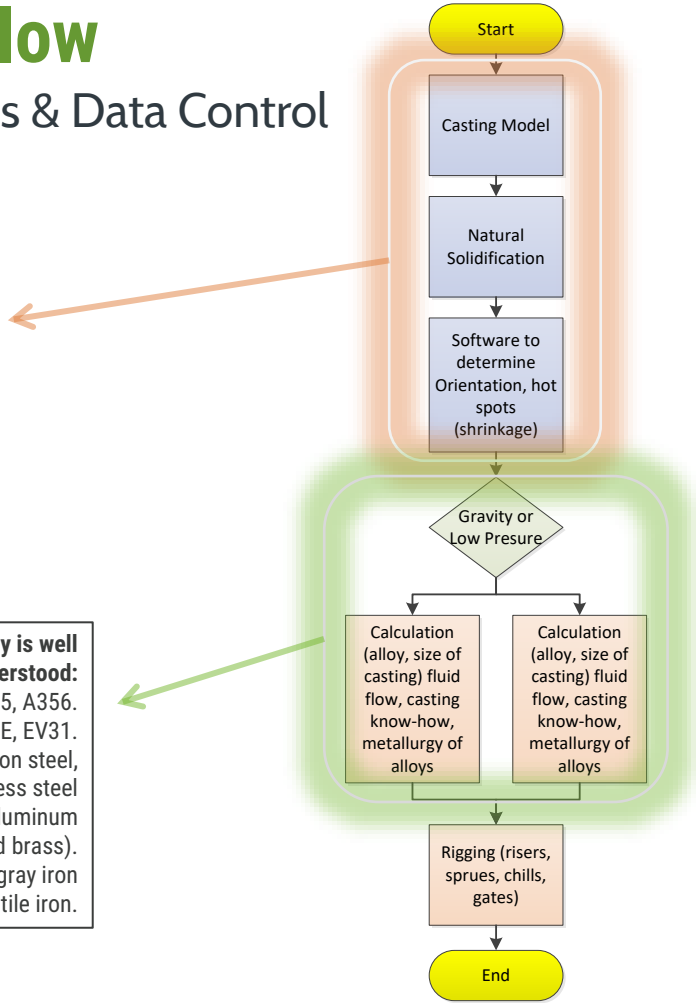
Sand 3D Printing | Full Digital Workflow

Simulation › 3D Printing › Controlled Casting › Process & Data Control



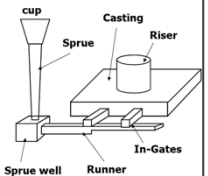


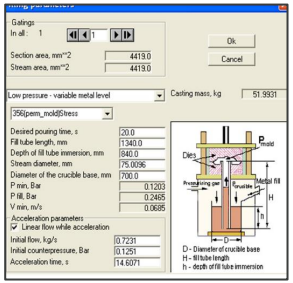




Unique Organic Gating and Risers

- **Components:**
  - **Pouring cup (or basin):** maintain a full system and control an initial velocity; adequate shape is crucial;
  - **Sprue:** tapered shape to prevent gas aspiration;
  - **Sprue well:** size depending on runner dimensions;
  - **Runner:** based on Bernoulli's Theorem should be "step-down" and have an extension(tapered) and a vent;
  - **In-Gates:** size depending on casting weight and to provide a laminar flow in the casting





Alloys where metallurgy is well understood:
Aluminum alloys: E357, C355, A356. Magnesium alloys: AZ91E, EV31. Invar 42: Invar 36. Various carbon steel, low alloyed steel and stainless steel alloys. Various Cu alloys(aluminum bronze, Cu-Ni, red leaded brass). Various types and grades of gray iron and ductile iron.

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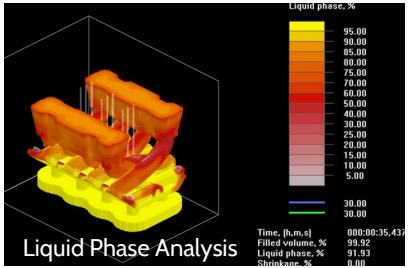
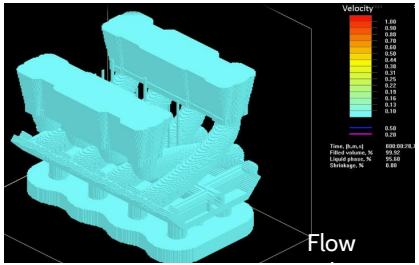
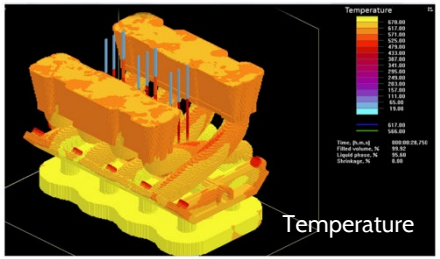
Sand 3D Printing | Full Digital Workflow

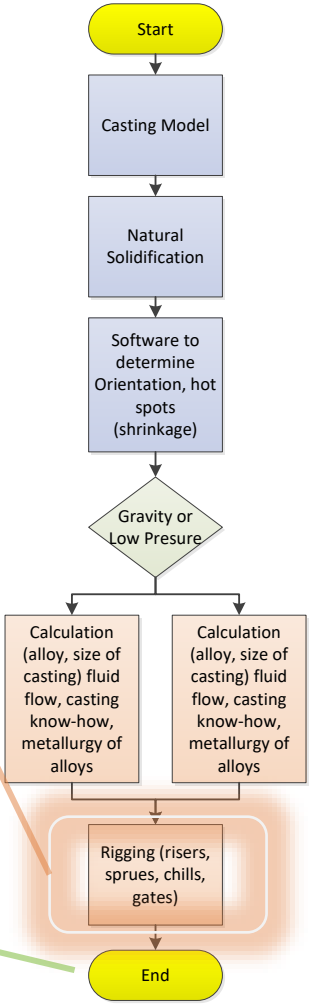
Simulation › 3D Printing › Controlled Casting › Process & Data Control







Casting



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Sand 3D Printing | Transformational Benefits

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

OEMs and foundries optimize business with binder jetting to deliver castings with complex designs and fast turnarounds, while saving money on patterns, molds, and labor.

SPEED

Reduce delivery times

- Regardless of complexity, deliver molds and cores within hours or days, not the weeks and months needed for traditionally manufactured patterns

SAVINGS

Eliminate patterns, molds, and labor

- Eliminate the added time, labor, and expense of mold creation, extraction, repair, and assembly and deliver complex cores at a lower total cost than core shooters

NO PATTERN STORAGE

Replace physical inventory with digital storage

- Print direct from CAD files without the need to store patterns or molds for core shooters while removing the risk of lost patterns or repair for degraded molds

RAPID DESIGN CHANGES

Improve designs without a cost penalty

- Save time and money while reducing waste and optimizing designs by iterating instantly without scrapping existing or creating new patterns and molds for core shooters

EXCEPTIONAL DESIGN FREEDOM

Optimize final parts and mold package design

- Complex and organic geometries for both final parts and rigging and riser design deliver higher-quality castings and enable low-pressure pouring at no extra cost

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Sand 3D Printing | Speed & Quality Improvements

New designs are now possible for metalcast 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

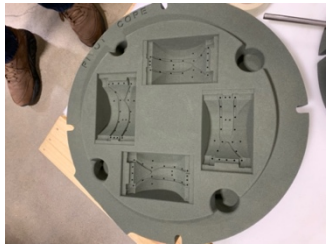
Time to First Pour | Time to Delivered Part

SIKORSKY
A LOCKHEED MARTIN COMPANY

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

Done-in-One Pour (Aluminum)

Altair

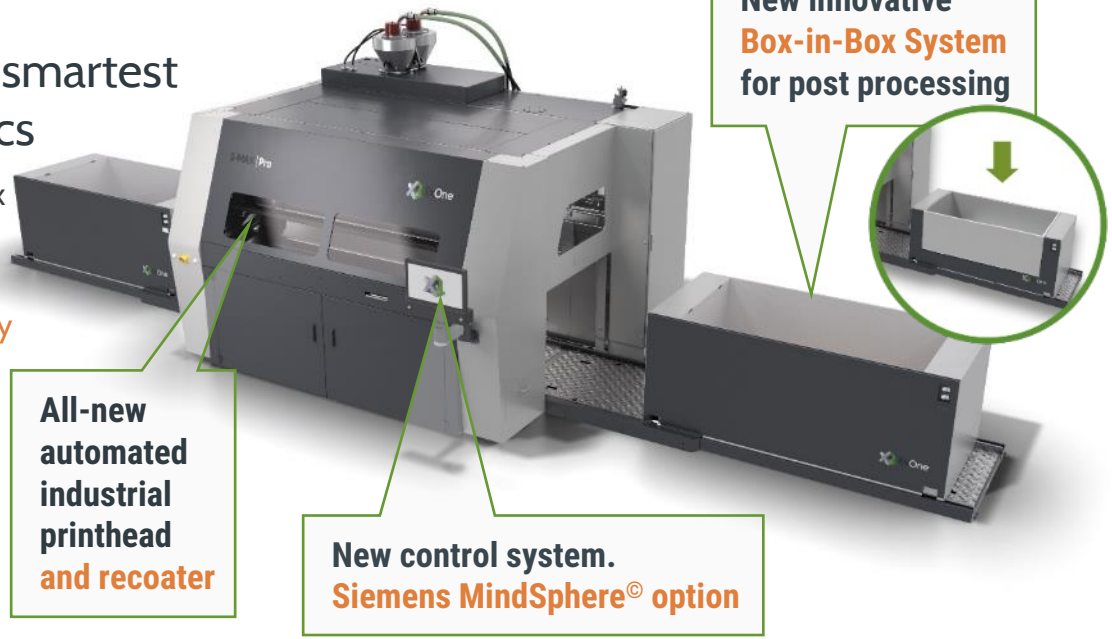


ExOne

ExOne | S-Max® Pro

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

- Double job box or interchangeable box-in-box
- 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



TECHNICAL SPECIFICATIONS

External Dimensions: (L x W x H)	10400 x 3520 x 2860 mm (409.5 x 138.6 x 112.6 in)
Job 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	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 m³/h	600 m³/h	600 m³/h	300 m³/h

** With Box-in-Box System 400 mm height*

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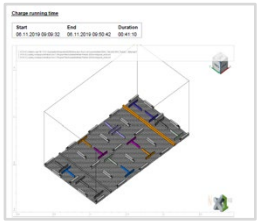
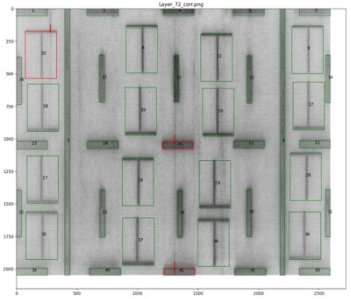
** depending on job box utilization, sand type, layer height, resolution & environmental conditions*

ExOne Quality System Enabled by Siemens

1. Process Quality Assurance with Siemens Industrial Edge©

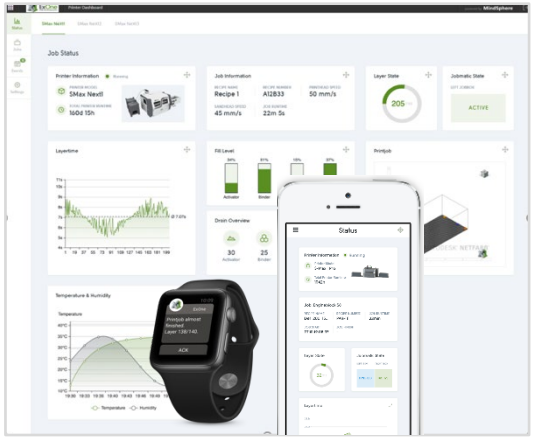
- Edge camera takes pictures of every printed layer
- Pictures stored on the Edge device HD for manual inspection via derived flip book video
- Outlook: New Edge computing app with self learning AI algorithm for automated defect detection and reporting to starting beta Q2/2021





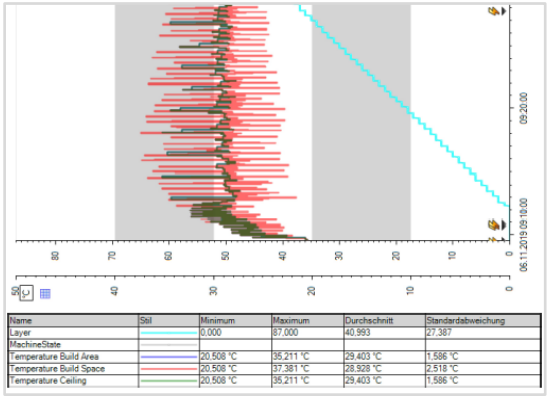
2. Cloud Monitoring with ExOne Scout App and Siemens MindSphere©

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



3. Process Optimization with Siemens PM Quality© SW

- Process & machine data logging on SQL data base
- Job-to-Job analysis
- Statistic process optimization
- 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

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Sand 3D Printing | Binders and Materials

A variety of binder systems tailored to casting needs

- Organic
- Solvent
- Water
- Inorganic

	Print +	Microwave	or	Oven
FB001 – Furan Steel, iron, non-ferrous metal, aluminum	● ●	✓		
FB901 – Inorganic 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	● ●	✓		✓

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Binder System Comparison

	Furan	CHP	HHP	IOB
Molding material	Silica sand / synthetic sand	Silica sand	Synthetic sand	Silica sand / synthetic sand
Strength [N/cm²]	> 200 / < 400 N/cm²	200 – 350 N/cm²	< 600 N/cm²	> 200 / < 350 N/cm²
LOI [%]	- 1.7 – 2.1 %	- 1.4 – 2.1 %	- 1,5 – 2.1 %	-
Melding temp. [°C]	< 1550°C / < 1850°C *	< 1550°C *	< 1850°C *	< 900°C *
Accuracy	+/- 0.5 mm **	+/- 0.5 mm **	+/- 0.5 mm **	+/- 0.5 mm **
Suitable material	non-ferrous metal / iron casting material / steel	non-ferrous metal / iron casting material / steel	Iron casting material / steel	Non-ferrous metal / light metal
Decore * **	3	2	3	1
Precoating possibility	Yes	Yes	Yes	Partly
Storage	Up to 8 weeks max.	Up to 2 weeks max. after this time renewable with oven treatment again	Up to 4 weeks max.	Storage in a drying room is possible
Post process	No	Oven drying	Microwave drying	Microwave drying
Cost / Liter * (Standard combinations)**	1	2	4	2

* Depending on wall thickness
** Depending on the size and geometry of the component (up to 0.1% of the component size possible)
*** Grade system (1 = A, 6 = F)

ExOne

Beyond 3D Printing | OneCast Sandcasting Solutions

Full 360° support from combined binder jet and metalcasting experts

VIRTUAL CASTING WITH SOLIDIFICATION MODELING

- Simulate solidification to determine hot spots
- Calculate rigging system components to optimize pour velocity and perform fluid flow and solidification modeling
- Iterate designs quickly without trial castings

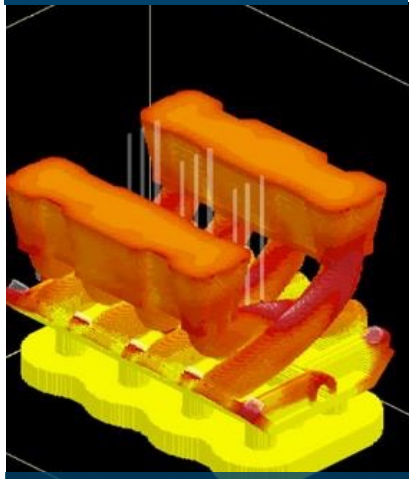
DESIGN AND ENGINEERING

- Complex mold and core package design
- Optimize rigging and riser designs and enhance castings with elements such as hyperbolic sprues and bottom gates

SUPPORTING OEMs, FOUNDRIES, PATTERN SHOPS, & DESIGNERS

- Sand 3D printing and foundry sourcing
- Full inspection services
- On-site pour supervision
- Training for digital mold package design

VIRTUAL CASTING MODELING



Liquid phase analysis of a virtual casting model to optimize rigging design

OPTIMIZE FROM CAD TO CAST

New possibilities for complex geometries and done in-one-pour, high-quality castings

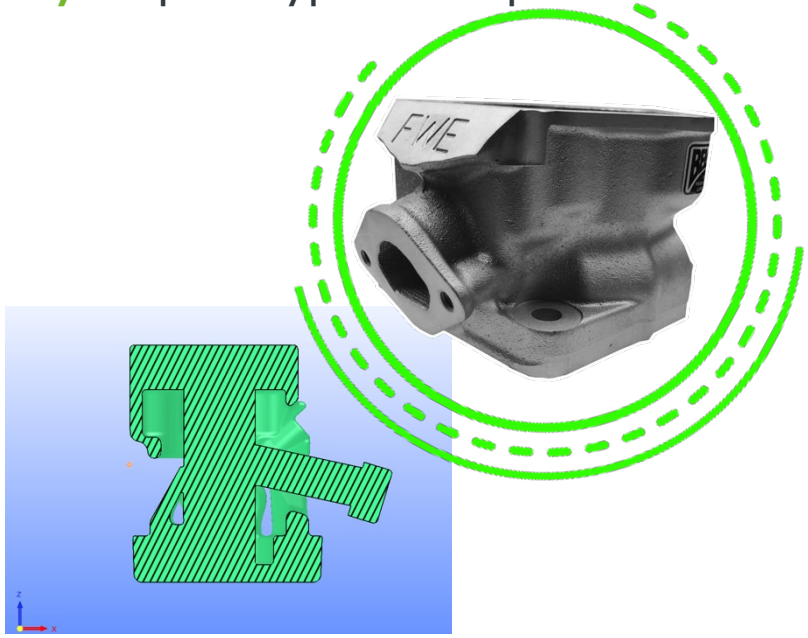
SAND 3D PRINTING CASE STUDIES

Binder Jetting | Fast Iterations and Serial Production

Eliminating core boxes **saves cost** and offers **flexibility** for prototype development

INDUSTRY Recreational equipment
APPLICATION Dirt bike cylinder
LOCATION Hoosier Pattern; Decatur, Indiana
CHALLENGE Previously produced with a traditional pattern and core box, which had long lead times and prevented the development team from testing new designs and iterating for improved performance

SOLUTION
3D PRINTING ExOne S-Max® production at Hoosier Pattern
MATERIAL Printed silica sand with furan binder for aluminum casting
SIZE/SPEED 5.25 x 4 x 4.75”
PRINT SPEED 144 molds per layer / 48 molds per hour
BENEFITS The complex component integrated the water jacket, intake, and exhaust, making it ideal for binder jetting. Each year, Hoosier receives a variety of prototype designs to quickly print and have cast for performance testing. Making the switch to production 3D printed cores in 2015, this customer has cast thousands of parts with continuous design optimizations while the core boxes remain in storage.



“There’s a lot going on in this part, but that’s the beauty of printing sand. They’re not changing anything that requires a tooling investment. The core boxes are collecting dust while they just tweak the model to get what they want.”

Dave Rittmeyer, Customer Care & Additive Manufacturing Manager, Hoosier Pattern

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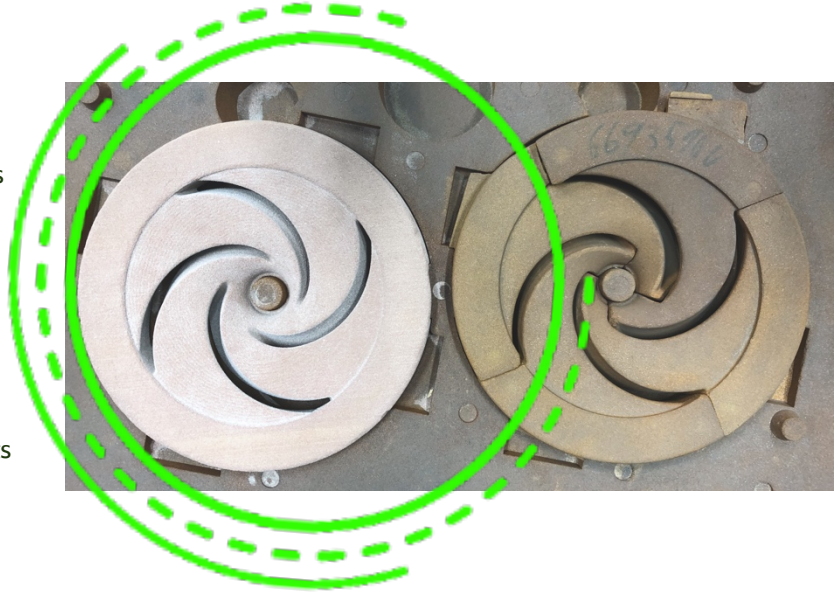
Binder Jetting | Reduced Assembly Increases Yield

Monolithic core optimizes production while driving down costs

INDUSTRY Water Treatment and Pumps
APPLICATION Impeller cores
LOCATION Sweden
CHALLENGE Goal to speed up production while optimizing product and process. Traditional core shooting took seven days to manufacture impeller cores in four parts glued together with core gum.

SOLUTION
3D PRINTER ExOne S-Max®
MATERIAL Printed silica sand with CHP binder for iron casting
COST Overall production costs decreased ~30%
BENEFITS One-piece design only possible with binder jetting eliminated the process step of gluing core parts together while also increasing yield since gas pockets caused by core gum no longer caused defects. Production is also faster as post-processing is reduced since the printed impeller has no drafts and up to 480 cores can be printed in one 24-hour process.



"The quality of the impeller cores has improved significantly through the 3D printing process. At the same time, the production costs have decreased by around 30%"

Torbjörn Andersson, 3D Technician at Xylem

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Binder Jetting | 2019 AFS Casting of the Year

3D printed complex core saves thousands in tooling costs and reduces lead times by weeks

INDUSTRY Heavy Equipment
APPLICATION Compact utility tractor swing frame
CHALLENGE Amerequip required a conversion of an 11-piece, lasercut welded assembly to reduce weight, improve quality, and minimize cost through improved production efficiencies with a one-piece design. With a tight schedule that risked missing the deadline for next season's production, Amerequip turned to Neenah Foundry to created the single ductile iron casting design made using a single low-cost core 3D printed at Hoosier Pattern

SOLUTION
3D PRINTER ExOne S-Max®
MATERIAL Printed silica sand with furan binder for ductile iron casting
LEAD TIME Completed in less than 2 weeks
WEIGHT Reduced 2.2 lbs
COST Core box modification cost savings $5,000
BENEFITS Freedom of design allowed for a reduced assembly that also saved weight and tooling costs.

Design for Additive Manufacturing (DfAM) optimization created a one-piece component from 11 assembled parts. The speed of binder jetting the complex core enabled a final part to be delivered in under two weeks.

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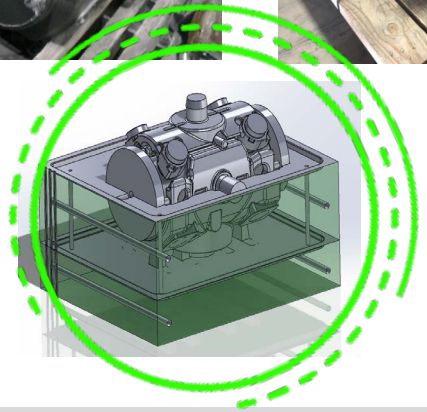
Binder Jetting | Decreased Lead Times

Complex mold production reduces lead times and saves costs

INDUSTRY Gas
APPLICATION Compressor cylinder
LOCATION Houston, Texas
CHALLENGE Required extremely fast lead time for a complicated casting geometry to replace cylinders on an obsolete compressor within two months and without tooling.

SOLUTION
3D PRINTER ExOne sand binder jetting
MATERIAL Printed silica sand with furan binder for class 40 cast iron
SIZE 46 x 38 x 46 assembled mold
COST Tooling costs eliminated from traditional pattern costs of $70,000
LEAD TIME 1 week to print vs 17+ weeks for traditional pattern production
BENEFITS Complex molds were printed in about one week and were ready for the casting pour to meet the aggressive 8 week delivery time.



By using ExOne technology, the complex mold was ready for the casting pour in 1 week to meet the aggressive delivery and enable compressor repairs to begin

METAL 3D PRINTING

ExOne | Comparing Final Part Density

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

EXONE BINDER JET 3D PRINTING PART DENSITIES

50%-60%

ExOne Pre-Sintering "Green" Part Density

ExOne Final Sintered Density (97-99% for most metals)

91% 92% 93% 94% 95% 96% 97% 98% 99% 100%

Press and Sinter or PM (85-93%)

Metal Injection Molding or MIM, (96-98%, w 98% being most common)

Metal Castings, Gravity (95-97%)

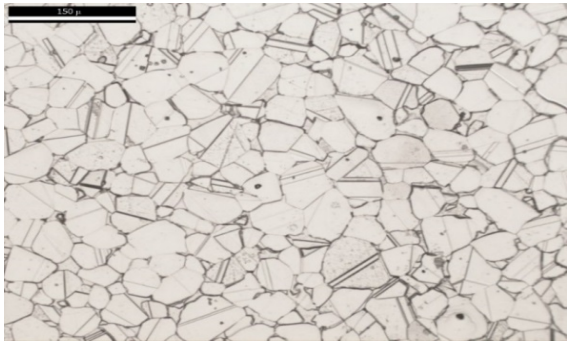
Metal Castings, Low Pressure (97-98%)

Wrought Parts (>98%)

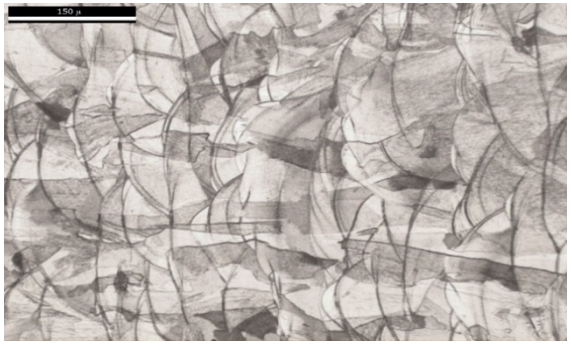
TRADITIONALLY MANUFACTURED PART DENSITIES

Metal 3D Printing | High Density, Superior 3D Microstructures

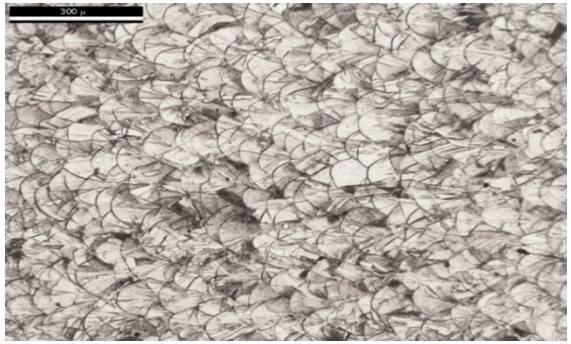
Why? Binder jetting 3D prints parts without particle fusion until final sintering



Binder Jetting



EBM



DMLS

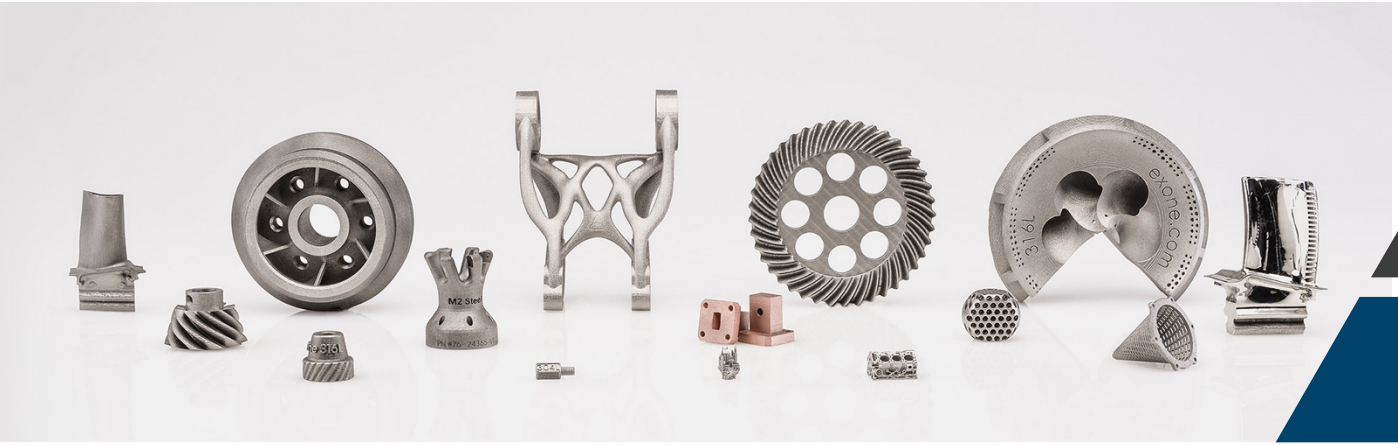
- Equiaxed grain structure for binder jetting leads to isotropic material properties (30 to 60µm grain size)
- Tiered, columnar grain structure for EBM and DMLS (80 to 400µm grain size)
- Minimal chemical segregation at grain boundary in binder jetting parts due to room temperature processing
- Binder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

ExOne

Binder Jetting | Material Flexibility & Qualification

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

- Durable tooling materials for metal tools: 420i, 316L, M2 qualified
- Customer Qualified: H11, Aluminum 6061 and more
- In Development: H13, 4140 and more



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

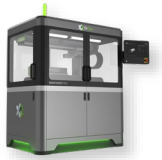
CUSTOMER-QUALIFIED: Qualified by customers with their own standards and being successfully 3D printed for their own applications.

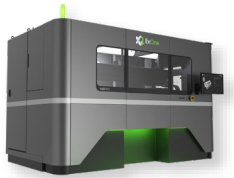
THIRD-PARTY QUALIFIED: Have passed rigorous tests over multiple builds and have verified material property data from an independent third party. General marketplace readiness.

ExOne

Metal 3D Printing | Product Overview

Binder jetting for metals, ceramics, and composite powders





	Innovent+®	M-Flex®	InventPro™	X1 25Pro®	X1 160Pro™
	✓ Research ✓ Prototyping ✓ Rapid product development ✓ Short-run production	✓ Research ✓ Prototyping ✓ Rapid product development ✓ Short-run production	✓ Research ✓ Prototyping ✓ Rapid product development ✓ Short-run production	✓ Research ✓ Prototyping ✓ Rapid product development ✓ Short-run production ✓ Continuous 24/7 production ✓ Serial production	✓ Research ✓ Prototyping ✓ Rapid product development ✓ Short-run production ✓ Continuous 24/7 production ✓ Serial production
Build envelope	160 x 65 x 65 mm (6.3 x 2.5 x 2.5 in)	400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)	125 x 220 x 100 / 200 mm (4.9 x 8.7 x 3.9 / 7.9 in)	400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)	800 x 500 x 400 mm (31.5 x 19.7 x 15.8 in)
Volume	676 cc	25L	2.75 L or 5.5 L	25L	160L
Max build rate	166 cc/hr	1,600 cc/hr	700 cc/hr	3,600 cc/hr	10,000+ cc/hr
Min layer height:	30-200 µm	50-200 µm	30-200 µm	30-200 µm	30-200 µm
Min powder size:	2 µm (d50)	15 µm (d50)	5 µm (d50)	5 µm (d50)	5 µm (d50)

PRELIMINARY

ExOne

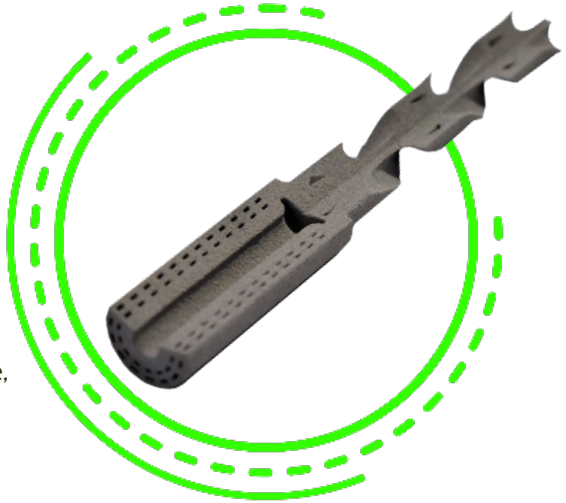
Case Study | Tool Steel & Hard Metal Cutting Tools

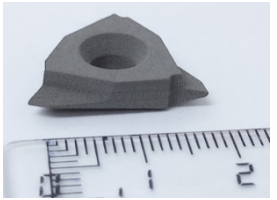
Processing challenging materials and integrating cooling channels without cost increase

INDUSTRY Tooling
APPLICATION Cutting tools; inserts and drills
LOCATION TECNALIA Research & Innovation; San Sebastián, Spain
CHALLENGE Investigate binder jetting of tungsten carbide cobalt (WC-Co) and M2 high-speed steel materials to develop tools able to withstand harsh in-service environments

SOLUTION
3D PRINTING ExOne Innovent®
MATERIAL WC-Co and M2
BENEFITS The flexibility of the Innovent allowed the team to print the challenging materials after an exhaustive selection and powder conditioning process optimized for the binder jetting process. The final parts provided were near net shape, reducing difficult and expensive machining and cutting lead times by 75%. The new functional designs enabled by additive manufacturing allowed embedding cooling channels to optimize the tools' temperature during operation.

tecnalia
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE





"After sintering, parts with densities comparable to traditionally manufactured commercial parts were obtained. In addition, the hardness and fracture toughness for the material was also comparable."
Dr. Iñigo Agote, Project Manager and Group Leader, TECNALIA

ExOne

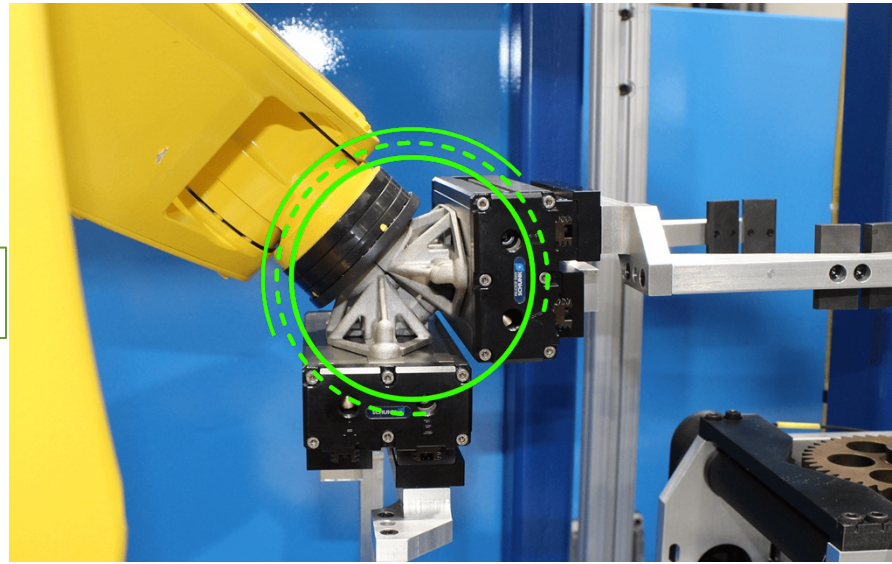
Binder Jetting | Lightweight Robotic Arm Tooling

Delivered affordable, durable and lightweight solution using less energy

INDUSTRY Automotive Parts Manufacturing
APPLICATION Robotics – End of Arm Tooling
LOCATION Saint Marys, PA
CHALLENGE Develop a strong, lightweight end of arm tooling attachment for a high-volume precision inspection application with varying weight requirements. The complex part enables two tools to sit at a 90-degree angle to each other on one arm.

SOLUTION
3D PRINTER ExOne Innovent+®
MATERIAL 17-4PH Stainless Steel (D90 of 22 µm)
PART SIZE 4.5 x 2 x 2 in. (12 x 5 x 5 cm)
WEIGHT 95 grams
COST $150 prior to finishing (compared to $672 for DMLS)
BENEFITS Generative software produced a lightweight design that could only be manufactured with 3D printing. Binder jetting was one-fourth the price of laser powder bed fusion. Final materials met MPIF standard 35 and customer requirements.

Read the full case study
Exone.com/EOAT



"It was one-fourth the cost of DMLS, and we did it in a strong material that reduced the payload on the robot. As Allegheny Electric Service rolls this technology out, it's going to be a bigger savings for their customers."

- Chris Aiello, VP, Business Development FreeFORM Technologies for Allegheny Electric Service

Binder Jetting | Full Thickness Stamping Die

This X1 MetalTool 420i was used to run off aluminum stampings

This high-density tool created in 420i at full thickness shows the wide applicability of binder jet 3D printing for durable high-volume tooling applications.

This tool was used to stamp aluminum components and did not reach a failure point in testing.

Our binder jetting technology is durable enough to directly 3D print extrusion dies, forging dies, and stamping, embossing, bending, and countersinking tools

X1 MetalTool is durable and flexible and can be considered for virtually any metal tooling application.

ExOne

X1 DIEMOLD

Still in Development: Direct 3D printing of X1 DieMolds

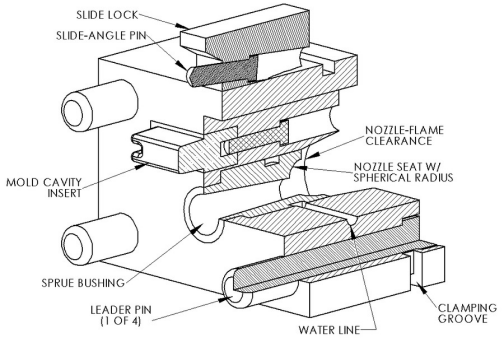
Several projects ongoing with **major manufacturers** to directly print die molds

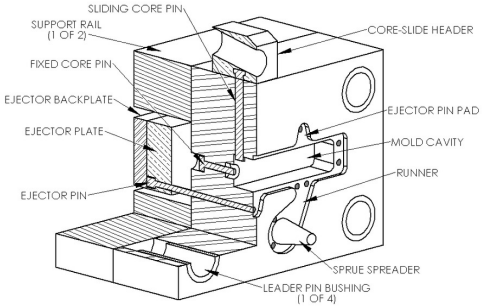
Binder jetting shows promise in directly 3D printing die molds for die casting operations, and we encourage any manufacturer with interest in using binder jetting for these applications to contact us directly.

Materials Being Developed for X1 DieMold tooling

- H11
- H13
- 420
- 4140

Sample Die Designs





Why Die Molds? Binder jetting can produce complex parts with ease.

X1 MetalTool is durable and flexible and can be considered for virtually any metal tooling application. We're confident that ExOne will be offering 3D printed die molds that offer all the benefits of our technology in other tooling areas, namely speed, geometric flexibility and affordability through reduced process steps.

ExOne

ExOne