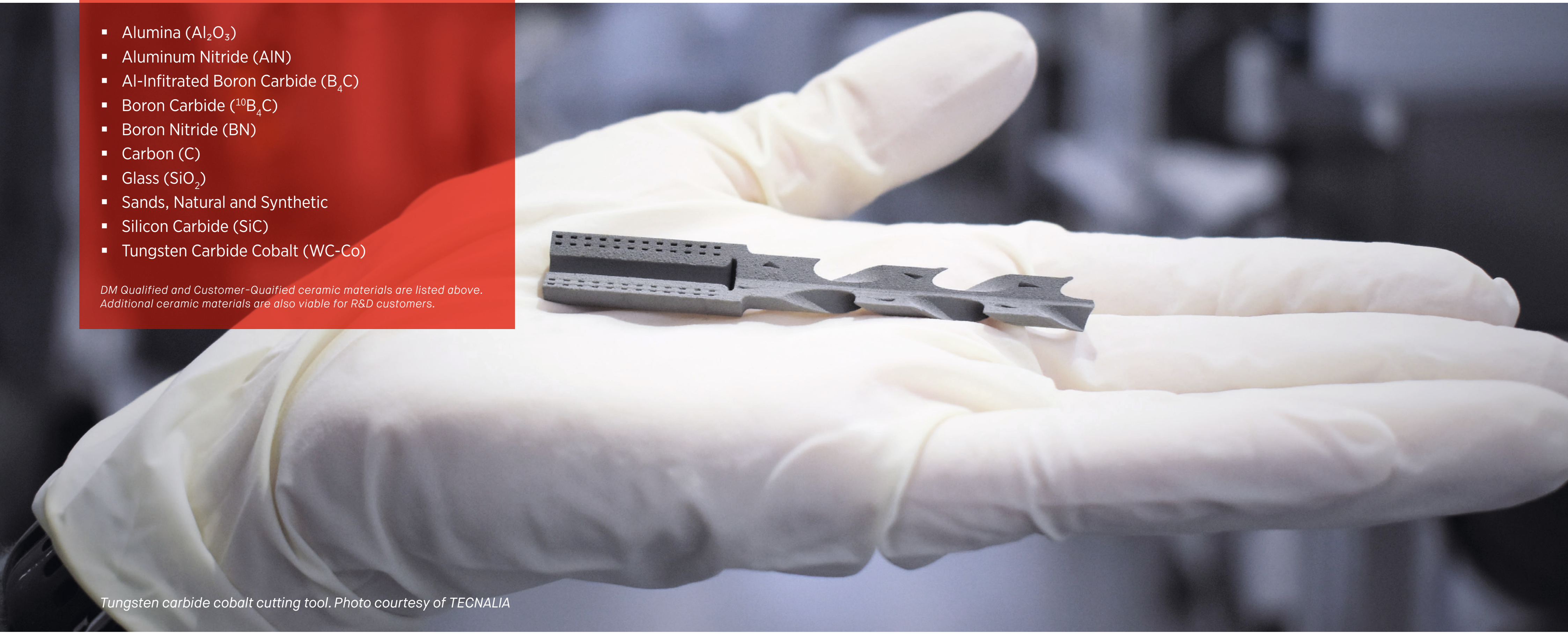
Desktop Metal

- Alumina (Al_2O_3)
- Aluminum Nitride (AlN)
- Al-Infitrated Boron Carbide (B_4C)
- Boron Carbide ($^{10}B_4C$)
- Boron Nitride (BN)
- Carbon (C)
- Glass (SiO_2)
- Sands, Natural and Synthetic
- Silicon Carbide (SiC)
- Tungsten Carbide Cobalt (WC-Co)

DM Qualified and Customer-Quaified ceramic materials are listed above. Additional ceramic materials are also viable for R&D customers.



Tungsten carbide cobalt cutting tool. Photo courtesy of TECNALIA

Ceramic 3D Printing with Binder Jetting

Benefits of Binder Jetting Ceramics

Simplified manufacturing of complex geometries with the following benefits

- High levels of
    - Hardness
    - Thermal conductivity
    - Thermal stability
- High resistance to
    - Abrasion
    - Chemicals
    - Corrosion
    - Erosion
    - Oxidation
    - Thermal expansion
- Reduces expensive material waste
- Enables new control of material properties via particle size and microstructure design

Tungsten carbide cobalt cutting tool. Photo courtesy of TECNALIA

Ceramic 3D Printing
The best kept secret in binder jetting

Across the Desktop Metal brand lineup, major manufacturers are 3D printing technical ceramic powders, including cermets, into a wide range of final products. Aside from commercial automotive components, our customers are making neutron collimators, nuclear fuel cell containment systems, hard cemented carbide tools for wear-resistant forming, cutting, and other applications, as well as aerospace sensing and imaging mirrors, optics, and other structures.

Forming technical ceramics the traditional way can be expensive, with long-lead time molds and expensive post-processing, such as precision cutting and grinding. Advanced, high-hardness ceramics often require an ultrahard diamond tool for precision finishing.

With the flexibility of binder jetting, however, creating precision technical ceramics, which can be sintered or infiltrated to create ceramic composites, is relatively easy. Virtually any geometry, regardless of complexity, can be created — bringing the many benefits of technical ceramics to new forms and products.

In binder jetting, an inkjet printhead selectively deposits a binder onto a thin layer of powdered particles, similar to printing on a sheet of paper, building a part one layer at a time. Our process delivers high accuracy, repeatability, and throughput — with consistent results suitable for mission-critical industries. Unbound powder is also typically reusable, further enhancing cost efficiency.

The flexibility of Desktop Metal binder jet systems allows manufacturers to print ceramics on our extra-large ExOne sand 3D printing systems as well as our Desktop Metal X-Series and Production System™ 3D printing platforms.

Simplify
Ceramic
Production

Customer Testimonials

For more than a decade, binder jet 3D printers have been used to produce ceramic parts across a wide range of industries. Below are comments from some of our trusted customer-partners in the ceramic binder jetting space.

tecnalia

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

"After sintering, (binder jetted) 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 Research & Innovation, a leading research institute, San Sebastián, Spain. Reference to tungsten carbide cobalt project. TECNALIA also binder jets silicon carbide.

JJ X-RAY

Danish Science Design

"We expect the advanced, intricate designs we can achieve with 3D printed collimators to open up new research opportunities and develop the field further.

Dr. Isja de Feijter, Application Specialist, JJ X-Ray, DTU Science Park in Denmark. Enriched boron carbide project. The team continues to work together with DM on infiltration with different materials like aluminum or cyanoacrylate.

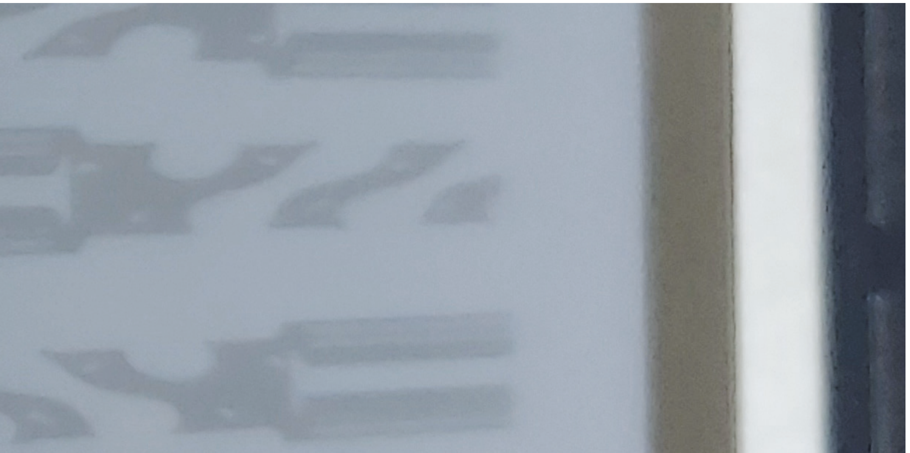
SGL Carbon says its 3D printing technology, developed and implemented on Desktop Metal's ExOne systems, is offered through its CARBOPRINT and SICAPRINT product lines. Learn more at TeamDM.com/SGL_Carbon

“Binder jet really shines. It is a low-cost and high-yield process for us as a part of our complex serial manufacturing.

Dr. Kurt A. Terrani, Executive Vice President, USNC's Core Division, and former National Technical Director, Oak Ridge National Laboratory. USNC is based in Seattle, Washington. Reference to silicon carbide project.

“We chose these machines because of the ability to develop applications for a variety of materials and then scale it within the machine family.

Nicholas Orf, Principal Scientist and Additive Manufacturing Group Leader at Saint-Gobain Research North America in Northborough, Massachusetts. Reference to silicon carbide project.



The image at left shows a closeup, overhead view of a tungsten carbide cobalt cutting tool being binder jet 3D printed by TECNALIA. Photo courtesy TECNALIA.

Case Studies

ULTRA-SAFE NUCLEAR CORP.

INDUSTRY
Nuclear

MATERIAL
Silicon Carbide

3D PRINTER
X160Pro, X25Pro, and InnoventX

PROCESS
Chemical Vapor Infiltration

CASE STUDY
TeamDM.com/USNC

Photo courtesy of USNC

Photo courtesy of Saint Gobain

SAINT GOBAIN RESEARCH NORTH AMERICA

INDUSTRY
Commercial Application Development

MATERIAL
Silicon Carbide + More

3D PRINTER
X25Pro, InnoventX

CASE STUDY
TeamDM.com/SGRN_SIC

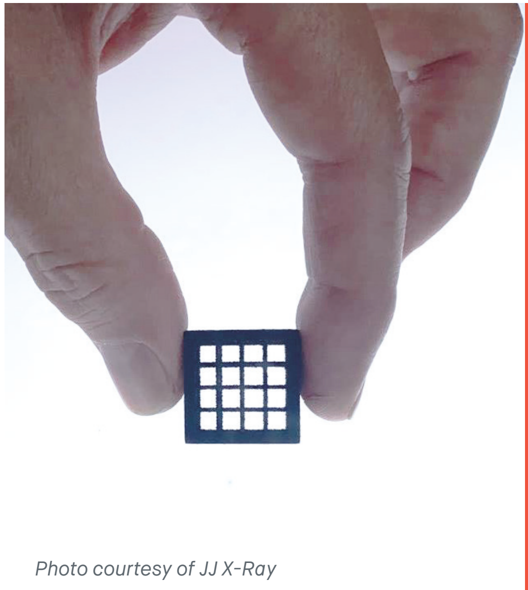


Photo courtesy of JJ X-Ray

JJ X-RAY

INDUSTRY
Energy - 2D Neutron Collimator

MATERIAL
Enriched Boron Carbide ($^{10}B^{4}C$)

3D PRINTER
InnoventX

CASE STUDY
TeamDM.com/JJXRAY_10B4C

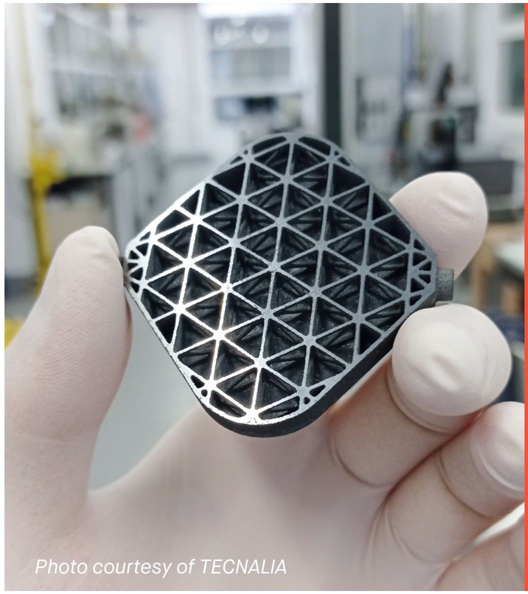


Photo courtesy of TECNALIA

TECNALIA

INDUSTRY
Aerospace - Satellite Optical Mirror

MATERIAL
Silicon Carbide

3D PRINTER
InnoventX

PROCESS
Capillary Liquid Silicon Infiltration (CLSI)

CASE STUDY
TeamDM.com/TECNALIA_SIC

Photo courtesy of TECNALIA

TECNALIA

INDUSTRY
Cutting Tools

MATERIAL
Tungsten Carbide Cobalt (WC-Co)

3D PRINTER
InnoventX

PROCESS
Sinter-HIP

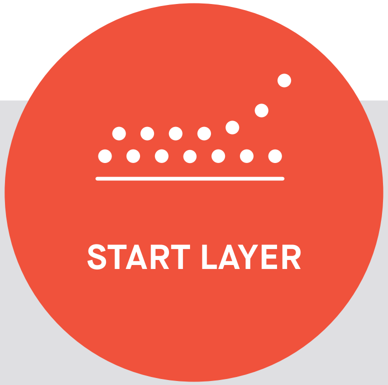
CASE STUDY
TeamDM.com/TECNALIA_WC-CO

The Binder Jet 3D Printing Process

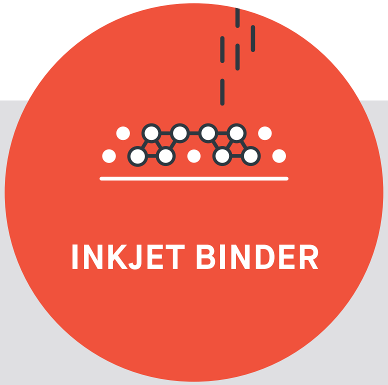
DIGITAL FILE PREP

MACHINE & MATERIAL PREP

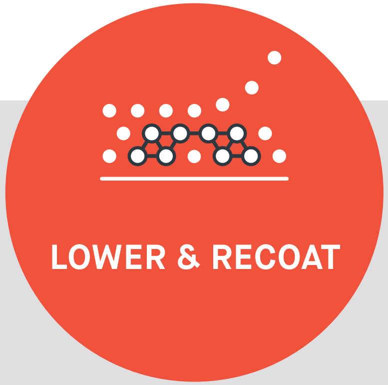
3D PRINTING



The recoater applies the first thin layers of powder — either ceramic, metal, or another material — in the print area or job box.



A gantry of industrial printheads selectively applies binder to the powder to bind particles together where desired. Different binders work with different materials to achieve desired results.



After each layer, the bed lowers for the next layer to be applied. Recoating is a critical step in binder jetting, as the consecutive powder layers must be precisely and compactly applied to deliver a high-quality precision part. Whether using coarse or fine particles, powder handling is a critical element of successful binder jetting.

Developed at MIT, commercialized by Desktop Metal and its Team DM brands, including ExOne. Fast and flexible, from materials to output types. Binder jetting is a method of 3D printing in which an industrial printhead quickly deposits a liquid bonding agent onto a thin layer of powdered particles, such as metals, foundry-grade silica, or ceramics. The process is repeated layer by layer using a map from a digital design file, until the object is complete.

RINSE & REPEAT

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

FAST LAYER SPEED

With a full sweep of printheads, 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 additive manufacturing methods.

PRINTING COMPLETE

Once the print job has finished, parts can be removed from the print area or job box. Depending on the material and binder used, additional curing and post-processing steps may be necessary. For certain sand binders, parts should be cured in an oven or microwave. Metal parts typically require curing and sintering.

CERAMIC POST-PROCESSING OPTIONS >>

Post-Print Design Control

With its wide, scalable gantry of printheads bonding a full layer together, binder jetting is regarded as one of the fastest forms of 3D printing for volumetric output. That helps manufacturers deliver sustainable, innovative designs with less waste at high volumes.

But that’s just one of the many reasons binder jetting is so incredibly attractive. When you’re 3D printing powder at low temperatures without melting, as you do with binder jetting, you also have incredible flexibility and control in materials and product forms or, as we like to say, output types.

Binder jetting allows you to print a precise form and also dial in the structure of that form in new ways that few other forms of additive manufacturing, or even traditional manufacturing, can do.

Desktop Metal’s team has a long history in binder jetting development to thank for its understanding of these output types:

Bonded Parts are simply powder particles that are bonded together and require no further post-processing for their application. In sand 3D printing, this is a frequent output state for metalcasting when silica sand is bound with a binder such as furan.

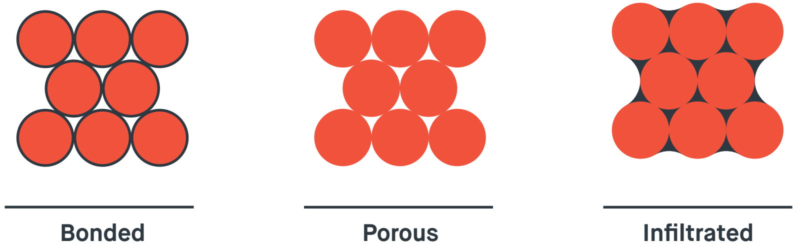
Porous Parts are lightly or partially sintered parts. Some applications with technical ceramics benefit from strong porous structures.

Infiltrated Parts are bonded or porous powder parts that have been infiltrated with another material. Infiltration is simply when another material is wicked into the printed form — similar to water being wicked into a sponge.

Infiltrated parts start off as a 3D printed form in the chosen material that is infiltrated with resins or other materials to create durable tooling, construction materials, and consumer products. For example, our tooling products start out as sand forms before they are infiltrated to make them durable for a variety of thermoforming, layup, or washout applications. The material flexibility of binder jetting is also leading to sustainable new products that use reclaimed waste material such as concrete or wood to shape unique furniture, instruments, or architectural designs before infiltrating them for strength.

LEARN MORE ABOUT INFILTRATED CERAMICS >>

OVERVIEW OF OUTPUT TYPES



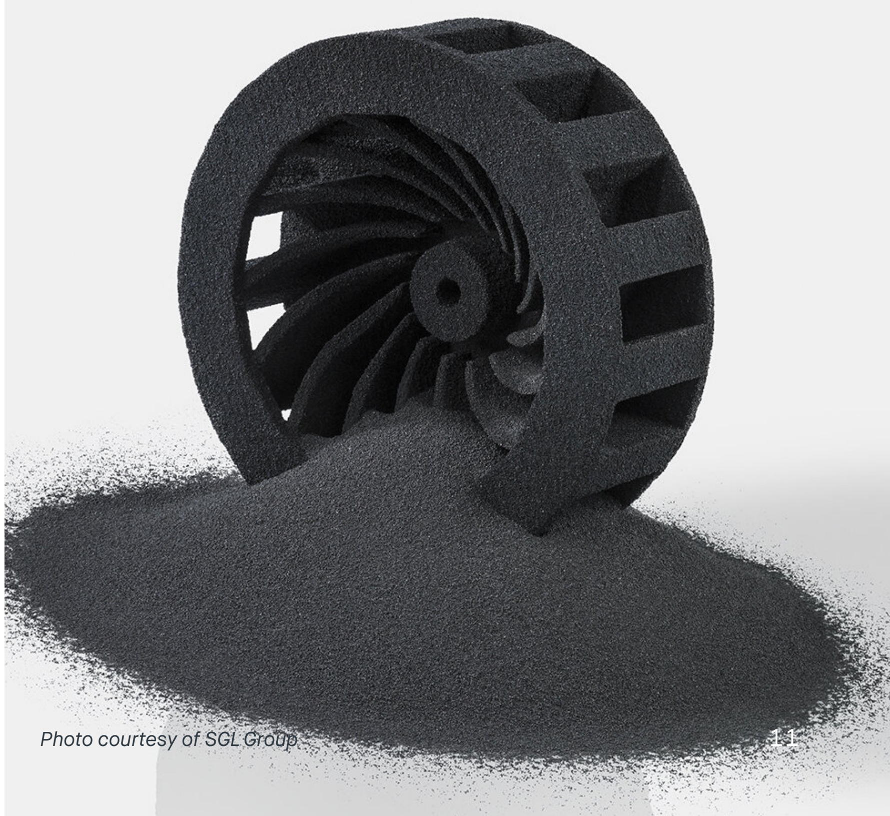


Photo courtesy of SGL Group

A New World of Ceramic Possibilities

ORNL's lab space will be vital for supporting future needs from advanced reactor developers to deploy the next generation of passively-safe nuclear operations and will be available to support other AM SiC development under the DOE-NE AMMT program.

The Desktop Metal X25Pro at Oak Ridge National Laboratory alongside chemical vapor infiltration equipment for processing silicon carbide.
Learn more at
TeamDM.com/ORNL_25PROSIC

Post-Printing Options

- High-Density Sintering
- Reaction Bonding
- Physical Vapor Deposition (PVD)
- Chemical Vapor Infiltration (CVI)
- Capillary Liquid Silicon Infiltration (CLSI)
- Polymer Impregnation and Pyrolysis (PIP)
- Among others

Binder jetting enables production of complex shapes and internal structures that are difficult or impossible to achieve with traditional methods.

Intricate geometries, such as hollow structures and lattices, are possible without complex tooling. Final parts can also be porous or high-density, and various composite types are also possible. Binder jetting allows the ability to tailor the porosity and microstructure of a part by controlling the particle size and binder droplet strategy — what's more, it allows for a wide range of post-processing opportunities as shown to the right.

Material flexibility

A wide range of powder sizes, shapes, and material types can be processed, including many not mentioned here. Contact us to inquire about your material.

Low-temp fabrication

Because particles are formed into geometries without melting, there is a higher level of control in the process of designing material combinations.

Different form factors

By using different particle sizes and even special combinations of different powder distributions, you can control and design porosity for future process steps.

Range of build sizes

Finally, with binder jetting, you have a scalable approach that can produce extremely small or extremely large part forms, as offered in the ExOne S-Max®.

Silicon Carbide

The flexibility of binder jetting and its various output types allows for incredible agility in the design and formation of technical ceramics. The multiple ways our customers process silicon carbide demonstrate the possibilities that exist when binder jetting ceramic parts.

Direct sintering of silicon carbide is difficult, requiring high temperature and pressure to obtain a fully dense part. As such, several techniques have been developed to address the post-processing needs of SiC.

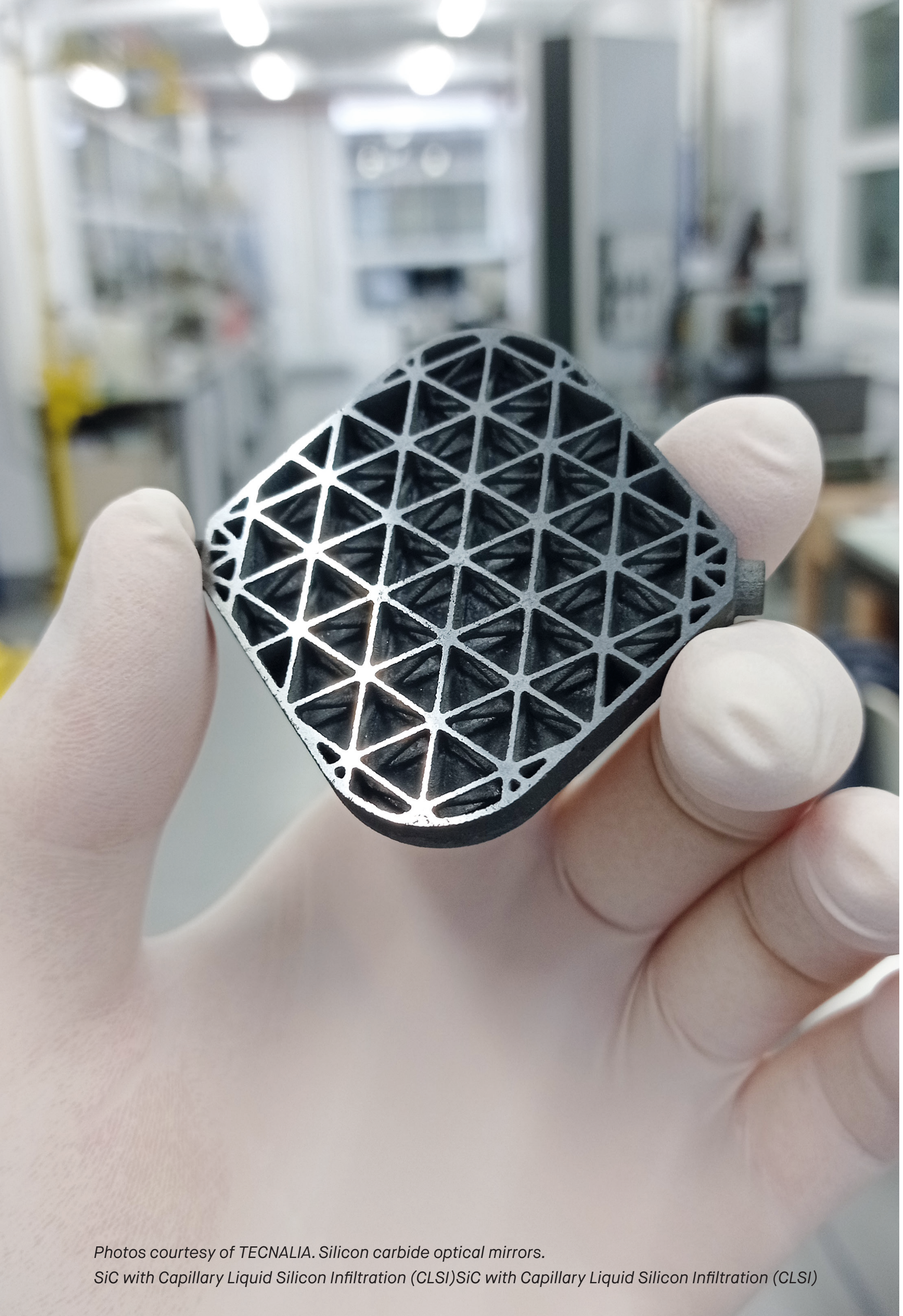
The most common post-processing method available is to infiltrate the printed and cured form or preform. This can be a liquid metal infiltration, either with silicon (SiSiC) or aluminum (AlSiC), a gaseous infiltrant (CVI) to create high density SiC, or other infiltrants to create unique matrices and microstructures (bonded SiC).

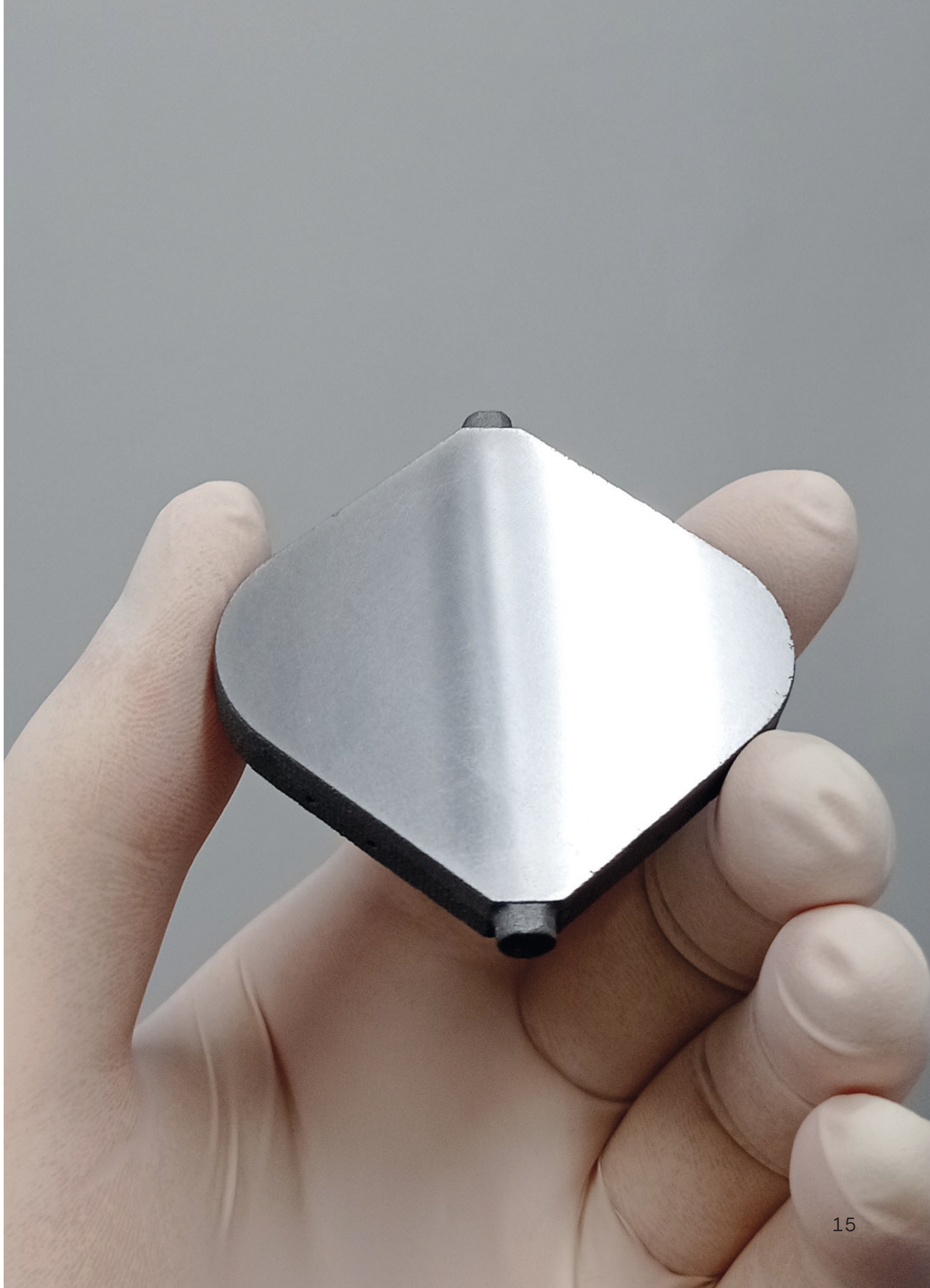
The relative quantities of liquid metal and residual carbon within the preform allow for more or less reaction bonding (RBSiC), shifting the balance of metal to silicon carbide. With CVI, the customer is left with a high-purity, nearly full-density, part whose properties are more in-line with conventionally processed SiC.

Finally, sintered silicon carbide may be realized from printed parts through the proper addition and use of sintering aids and pressure-less sintering techniques. Liquid phase additions such as alumina or yttria are most common, while carbon and boron carbide may also be used to enhance sinterability. High temperature processing is still required for silicon carbide densification, and is the least common post-processing method for binder jet 3D printed parts.

SiC Your Way

- SiC, reaction bonded (RBSiC)
- SiC, vapor deposition (PVD or CVI)
- SiC, liquid metal infiltrated (SiSiC or AlSiC)
- SiC, bonded (with materials such as nitride or mullite, usually for enhancement of properties)
- SiC, fully sintered





Photos courtesy of TECNALIA. Silicon carbide optical mirrors.
SiC with Capillary Liquid Silicon Infiltration (CLSI)SiC with Capillary Liquid Silicon Infiltration (CLSI)

Ceramic 3D Printers

All of these Desktop Metal binder jet 3D printers are currently printing ceramic materials for customers worldwide. Even if your material is not listed, our experts can help develop the printing parameters for your ceramic project.

InnoventX™

In production since 2016, this compact, easy-to-use system produces high-quality small parts

- Education and research
- Prototyping and rapid product development
- Short-run or batch production without tooling

Print technology	Triple ACT binder jetting	**Proprietary**	54 cc/hr at 65 µm layer thickness
Build envelope (L × W × H)	160 x 65 x 65 mm (6.3 x 2.5 x 2.5 in)	**Print resolution***	400 µm
Build volume	0.676 l (41 in³)		

X25Pro™

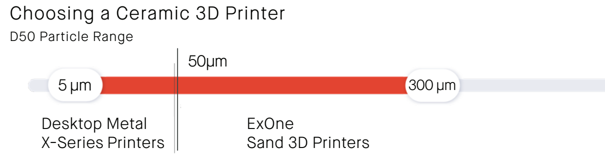
This flexible, mid-sized binder jet system can produce a wide range of geometries and help businesses scale from low to mid-volume production

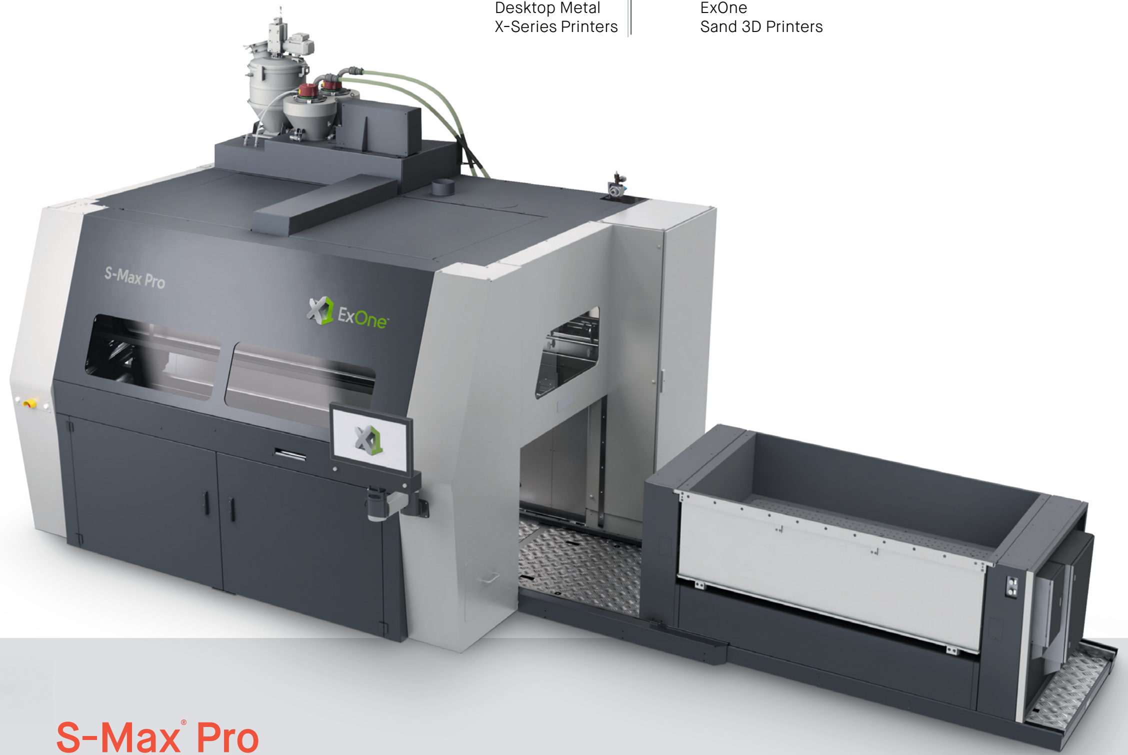
- Research
- Prototyping and rapid product development
- Scalable batch or bridge production without tooling

Print technology	Triple ACT binder jetting	**Proprietary**	1,200 cc/hr at 65 µm layer thickness
Build envelope (L × W × H)	400 x 250 x 250 mm (15.75 x 9.84 x 9.84 in)	**Print resolution***	400 µm
Build volume	25 l (1,526 in³)		

*Print resolution is based on using a 10 picoliter printhead and 30 µm layer. Results may vary on system configuration and materials used.

Choosing the right system for your ceramic project depends on your part size and throughput requirements, as well as the grain size of the ceramic powders you wish to process. Another consideration is the type of binder compatible with your powder, and how frequently you may wish to change materials.





X160Pro™

The largest commercially available binder jetting platform for the production of large parts and specialty materials

- World's largest binder jet build volume
- Prototyping and rapid product development
- Large or high-volume part production without tooling

Print technology	Triple ACT binder jetting	**Proprietary**	3,120 cc/hr at 65 µm layer thickness
Build envelope (L × W × H)	800 x 500 x 400 mm (31.5 x 19.7 x 15.8 in)	**Print resolution***	400 µm
Build volume	160 l (9,763 in³)		

S-Max® Pro

Our fastest and smartest sand printing system, primarily for foundry core and mold production, also used with other ceramics

- Remote monitoring options
- Interchangeable job box
- 24/7 production

Job box (L × W × H)	1,800 x 1,000 x 400/700 mm (70.9 × 39.4 × 27.6/15.8 in)	**Dimensional accuracy**	± 0.5 mm
Max throughput	145 l/h	**Print media**	Silica and ceramic sands
Layer thickness	0.2–0.5 mm	**Binder systems**	Furan, phenolic, inorganic

Multi-Material Powder Processing

In addition to our 3D printer portfolio, Desktop Metal also offers Selective Powder Deposition (SPD) technology through our Aerosint brand based in Belgium. This solution is currently aimed at the R&D community for research or development toward commercial solutions.

This patented multi-material technology, which can be integrated into an existing binder jet printing system, selectively deposits up to three different powders simultaneously to form a single layer containing several materials. This technology can be used with a wide range of powders, including **ceramics**, metals, and more, as well as different combinations of powder gradients.

Aerosint SPD technology offers the possibility of even more design control to enhance material properties in a binder jetting process. For example, improvements could be made in conductivity or insulation, wear or corrosion resistance, or magnetic performance.

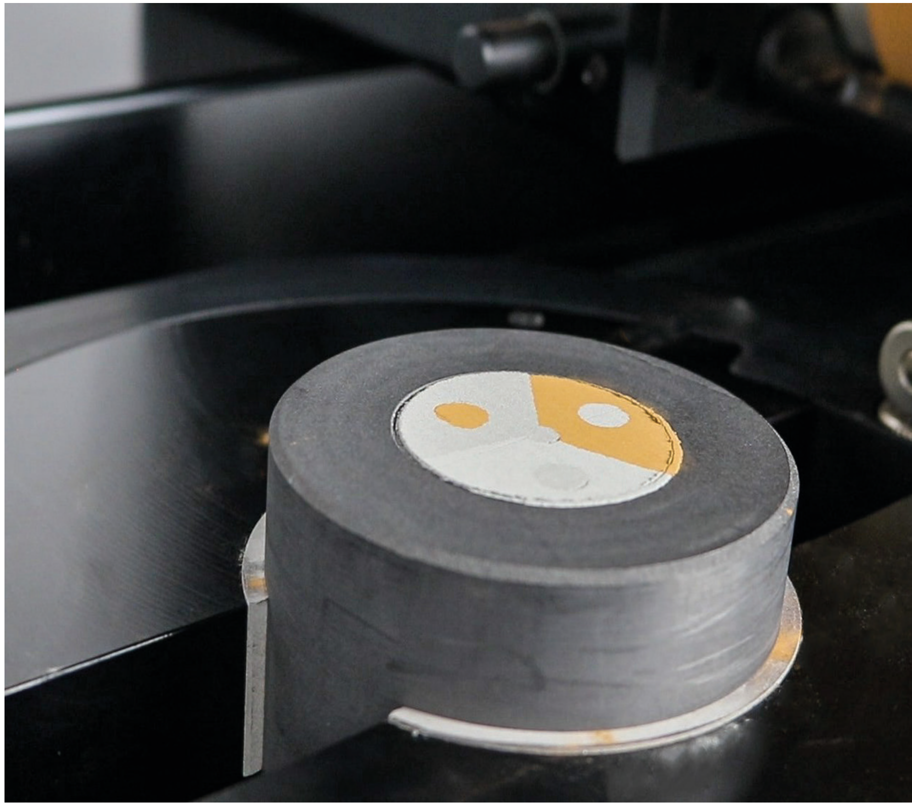
This unique technology unlocks new possibilities for ceramic printing. To learn more, contact a DM representative or visit TeamDM.com/aerosint.com

Binder Jet SPD Process

- Up to three different types of powders, including ceramics, can be deposited on the powder bed simultaneously
- Binder is added to the powder bed after each layer
- The process repeats layer by layer until the part is complete

▲ *Multi-Material Recoater*

▶ *At right, powder deposition of CuCrZr copper, 316L steel and Nickel-based alloy In625. The recoater can be used with ceramic powders as well as metals*



A True Partnership for Development

INDUSTRIES SERVED

- Automotive
- Aerospace
- Chemical Processing
- Electronics
- Energy
- Medical
- Nuclear
- Semiconductor

At Desktop Metal, our team has been working with a broad group of industries on binder jetting ceramics for more than a decade, and we have deep experience helping customers move from R&D and prototyping to full production.

Our work with the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) demonstrates our success in these partnerships. Desktop Metal's ExOne brand partnered with ORNL to develop a now commercialized, patent-pending method of 3D printing aluminum-infiltrated boron carbide (B_4C) for collimators and other components used in neutron imaging. Learn more about this project at **TeamDM.com/ORNL_B4C**

ORNL has also been instrumental in developing silicon carbide manufacturing on the X25Pro using chemical vapor infiltration. Learn more about this project at **TeamDM.com/ORNL_25PROSIC**

▲ *Desktop Metal has a commercial license agreement with the U.S. Department of Energy's Oak Ridge National Laboratory to 3D print parts in aluminum-infiltrated boron carbide (B_4C) using a patent-pending method developed on Desktop Metal binder jetting systems.*

▶ *Bianca Haberl (left) and Amy Elliott, both of ORNL, with parts printed in aluminum-infiltrated boron carbide (B_4C). Haberl is a neutron scattering scientist, while Elliott is a member of the R&D team for manufacturing systems research. Photo Credit: Genevieve Martin/Oak Ridge National Laboratory, U.S. Dept. of Energy.*

Partnership Process

Adopting cutting-edge technology can feel risky compared to just doing it the same old way. Our low-risk production adoption process helps to ensure your success. We help you determine if binder jetting is right for your application — from both a technical and business perspective — and we partner with you for the whole journey.

1. BENCHMARK & INITIAL QUALIFICATION
2. STATEMENT OF WORK
3. VALIDATE TECHNICAL & BUSINESS CASE
4. START OF PRODUCTION & DELIVERY PROCESS
5. WHITE-GLOVE WORK CELL DELIVERY

Evaluation of part for binder jetting

- Design & Geometry
- Material Properties
- Accuracy
- Functionality

Process optimization for parts

Our expert team optimizes our process for your part requirements, providing key details on timing, materials, recipe settings, etc. with complete testing.

Comprehensive executive report

A complete executive report and timeline is provided with details needed to validate both the technical and business case to proceed.

Production option selected, begins

- We can produce your parts long-term
- Or, proceed with purchase of binder jetting machines and customized work cells. We can print your parts until installation

Installation of Complete System

In line with final agreement, we install complete systems and execute first test runs. After acceptance is complete, we continue to support your operations and success.

This heat exchanger and gyroid, both reaction-bonded silicon carbide, were binder jet 3D printed on a Desktop Metal X-Series system.

Let's Connect

At Desktop Metal, our team has been working with a broad group of industries on binder jetting ceramics for more than a decade, and we have deep experience helping customers move from R&D and prototyping to full production.

When it comes to ceramics, which are often used for the most advanced technology applications, we recommend engaging with our most knowledgeable experts on your project.

Because of the broad flexibility of ceramic applications, including post-printing options, our specialized experts will work with you to understand your application and select and/or optimize the best powder sources, binders, and processes for binder jetting your solution.

We routinely work with companies providing commercial solutions, as well as governmental organizations, R&D departments, and educators on ceramics projects — in addition to other our materials, which includes metals (including reactive and precious metals), polymers, elastomers, foam, and upcycled materials, such as wood.

We invite you to engage with us on your project today.

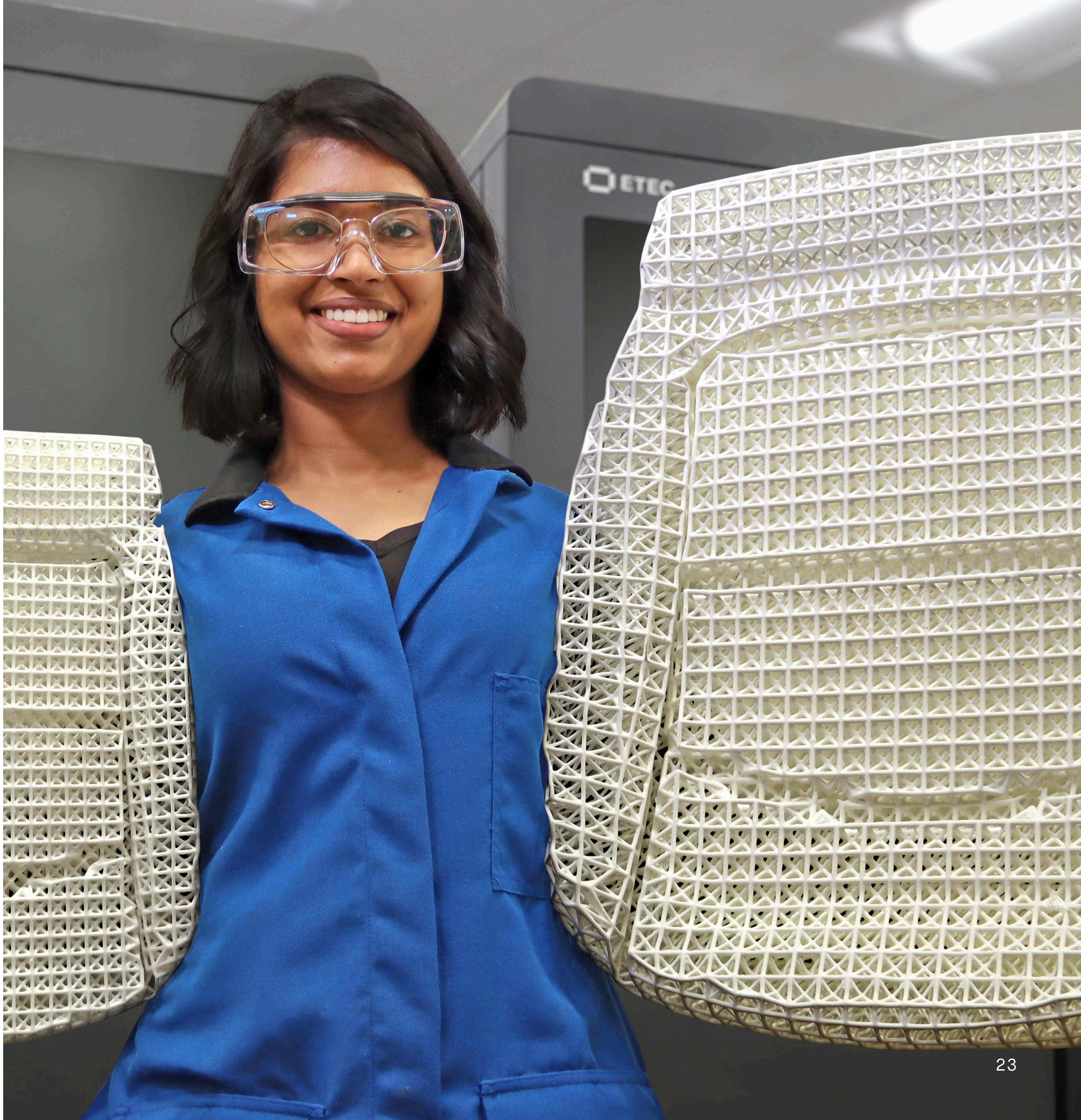
Contact Our Ceramic Experts

AMERICAS
Jamie Dolpies
Ceramics Lead,
Regional Account Manager
jamiedolpies@desktopmetal.com
T +1 603 866-6640
M +1 603 866-6640

EMEA
Oliver Hanitzsch
Ceramics Lead,
Regional Sales Manager
oliver.hanitzsch@exone.com
T +49 821 65063 370
M +49 160 93483 067

APAC
Ken Yokoyama
Director, ExOne KK
ken.yokoyama@exone.com
T +81 465 44 1303
M +81 80 3270 2649

#TeamDM


ETEC

Desktop Metal

Pictured above, employees of Ultra Safe Nuclear Corporation with a Desktop Metal X160Pro. Their system is binder jetting Silicon Carbide for use in USNC's innovative Fully Ceramic Micro-encapsulated (FCM) fuel. FCM fuel is enabled by Desktop Metal binder jet technology and its ability to 3D print silicon carbide heat-resistant ceramic particles in unique geometries that can safely surround a standard type of nuclear fuel particle known for its safety.

DesktopMetal.com
63 Third Avenue | Burlington, MA 01803
(978) 224.1244
#TeamDM | NYSE:DM