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 Niagara!97! 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 hardness
- High thermal conductivity
- High thermal stability
- High resistance to
- Abrasion
    - Chemicals
    - Corrosion
    - Erosion
    - Thermal expansion
    - Oxidation
- Reduce expensive material waste
- Tightly control material properties via particle size and microstructure

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 braking systems, 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 up 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.

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 smaller Desktop Metal X-Series 3D printing systems.

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.

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.

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

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

ULTRA SAFE NUCLEAR

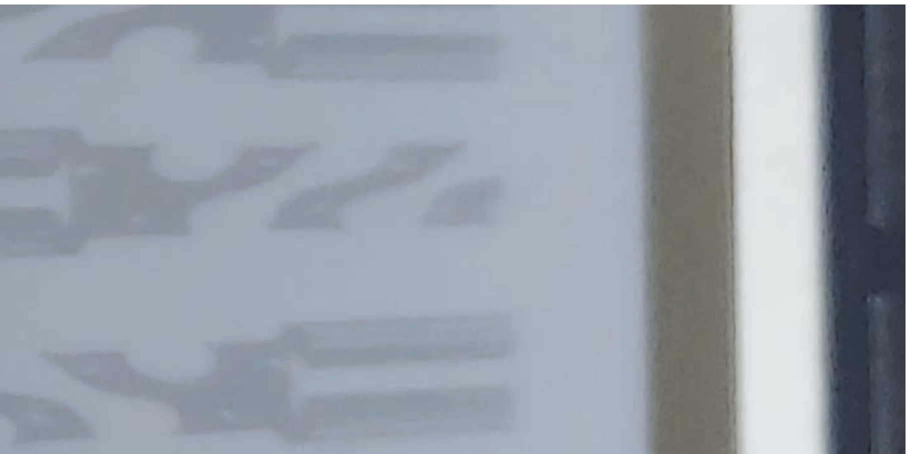
SAINT-GOBAIN

"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

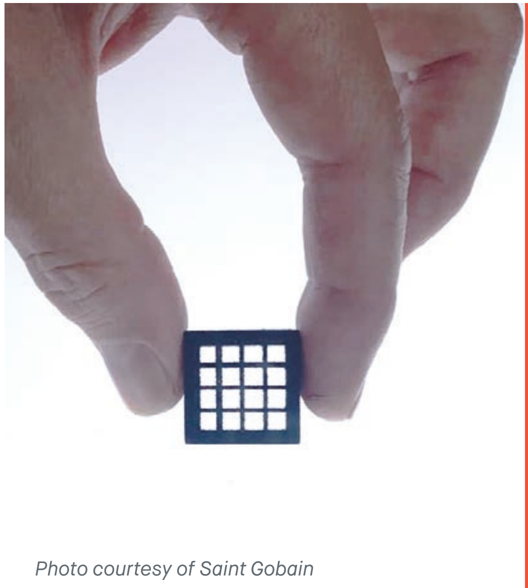


Photo courtesy of Saint Gobain

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

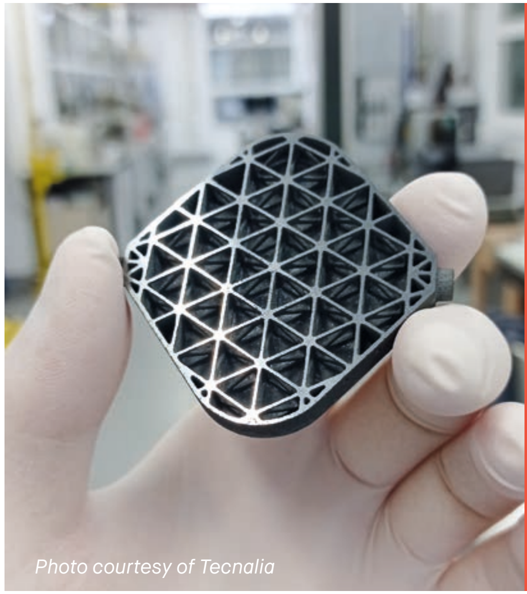


Photo courtesy of Tecnalia

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

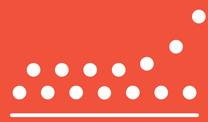
CASE STUDY
TeamDM.com/TECNALIA_WC-CO

The Binder Jetting Printing Process

DIGITAL FILE PREP

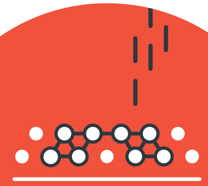
MACHINE & MATERIAL PREP

3D PRINTING



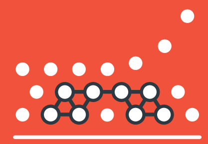
START LAYER

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



INKJET BINDER

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



LOWER & RECOAT

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.

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 part 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 not just to print a precise form, but to 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 bound powder particles that 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.

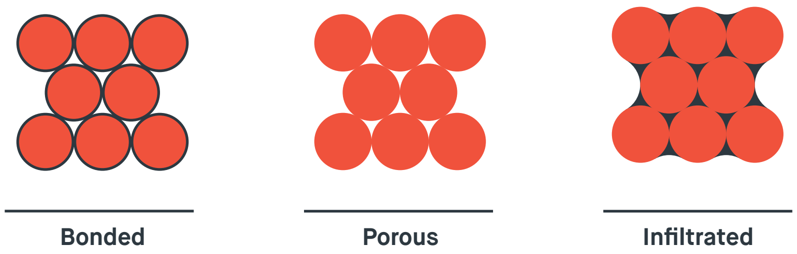
Porous Parts are lightly or partially sintered parts. Some applications with technical ceramics benefit from strong porous structures.

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 new sustainable 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 MATERIAL STATES



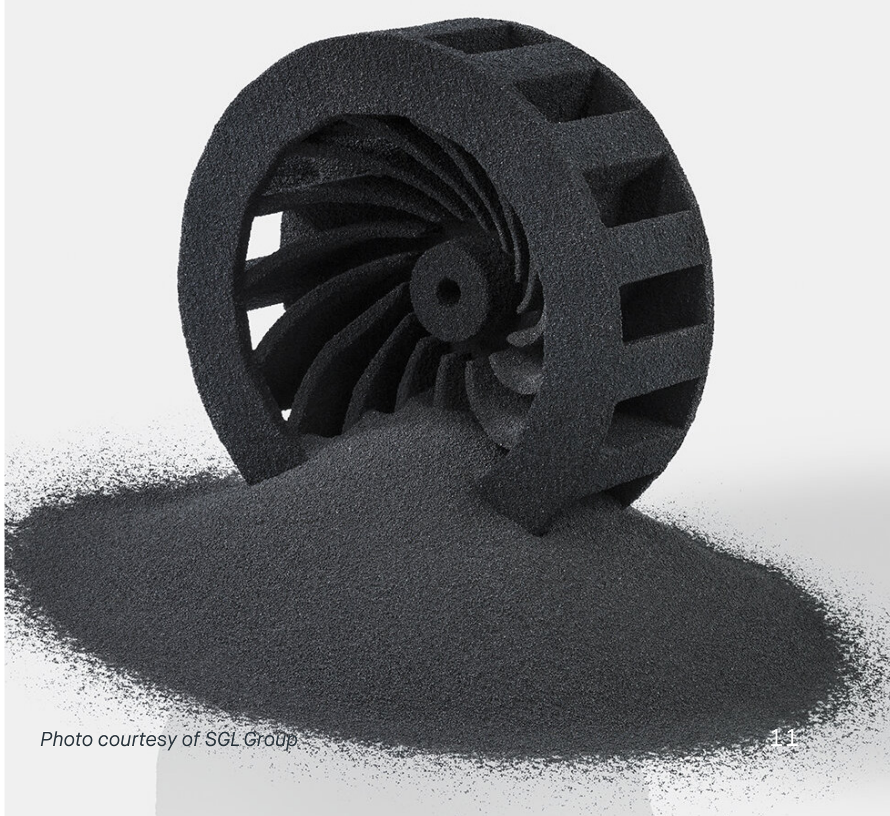


Photo courtesy of SGL Group

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.

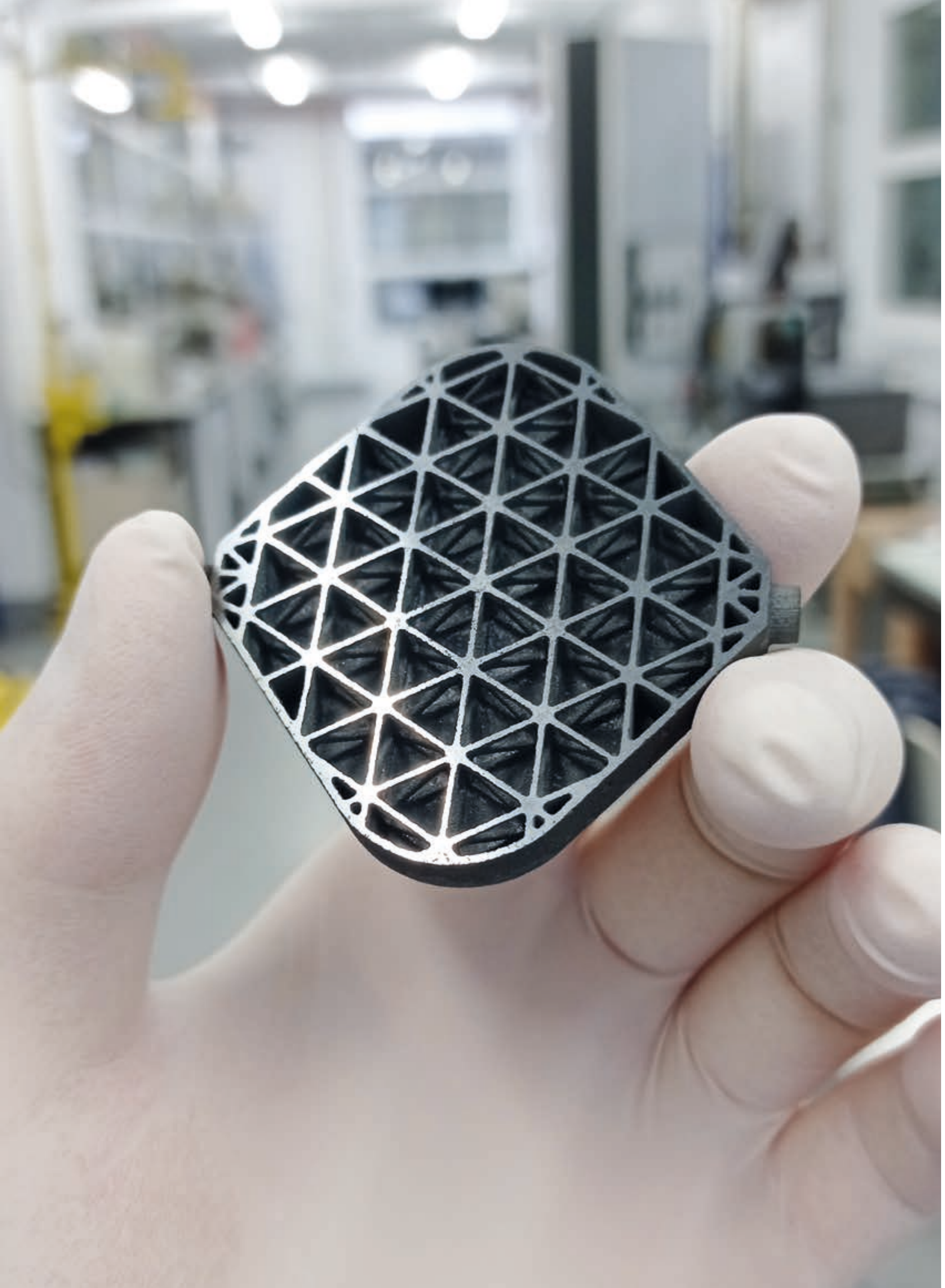
The most common post-processing method available is to infiltrate the printed and cured form or preform. This can be a liquid metal infiltration, either with silicon (SiSiC) or aluminum (AlSiC), a gaseous infiltrant (CVI) to create high density SiC, or other infiltrants to create unique matrices and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

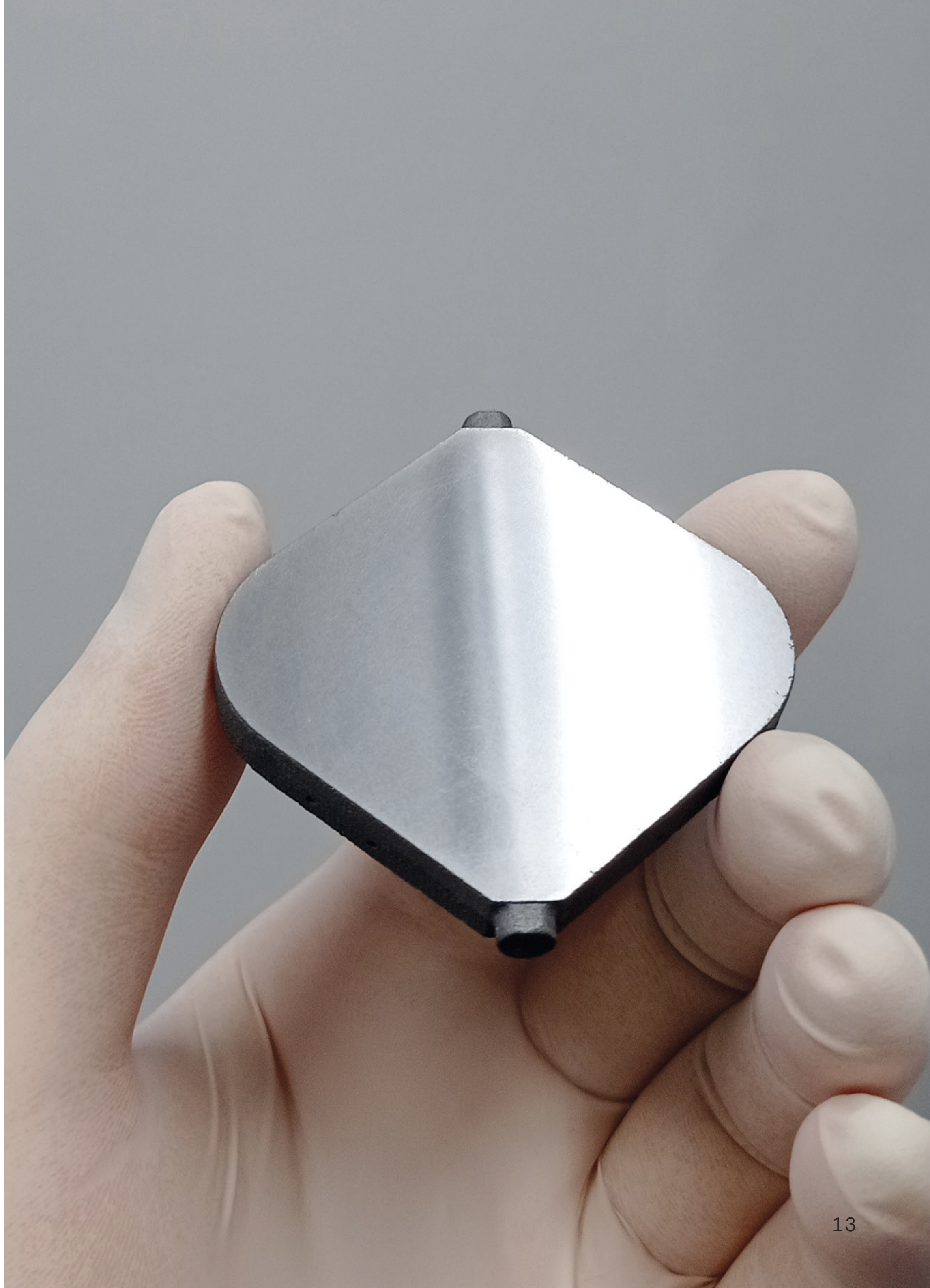
Finally, sintered silicon carbide may be realized from printed parts through the proper addition and use of sintering aids and pressure-less sintering techniques. Liquid phase additions such as alumina or yttria are most common, while carbon and boron carbide may also be used to enhance sinterability.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

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 via PVD, CVI)
- SiC (liquid metal infiltrated, SiSiC or AlSiC)
  SiC, Bonded (with materials such as nitride or mullite, usually for enhancement of properties
- Fully sintered





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

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

- Sintering
- Infiltrating
- 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, lattices, and porous or high-density materials, including various composite types, are possible without complex tooling. Binder jetting allows the ability to tailor the porosity and microstructure of a part by controlling the particle size and binder droplet strategy, not to mention it allows for a wide range of post-processing opportunities as shown to the right.

Material flexibility

A wide range of powders 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.

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™

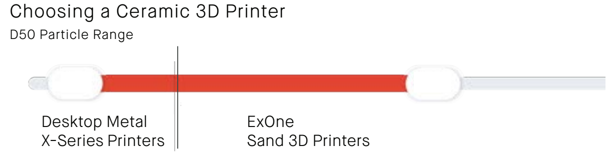
This flexible, mid-sized binder jet system can produce a wide range of geometries and help businesses scale from low to mid-volume production

- 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 system for core and mold production with the widest range of binders, including inorganic

- 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 system**	Furan, phenolic, inorganic

Multi-Ceramic Powder Processing

In addition to the Desktop Metal ceramics portfolio, the Selective Powder Deposition is a technology enabled by the multi-ceramic recoater which acts as a printhead and an alternative to single material recoating systems. It allows the precise deposition of multiple ceramic powders from a single layer.

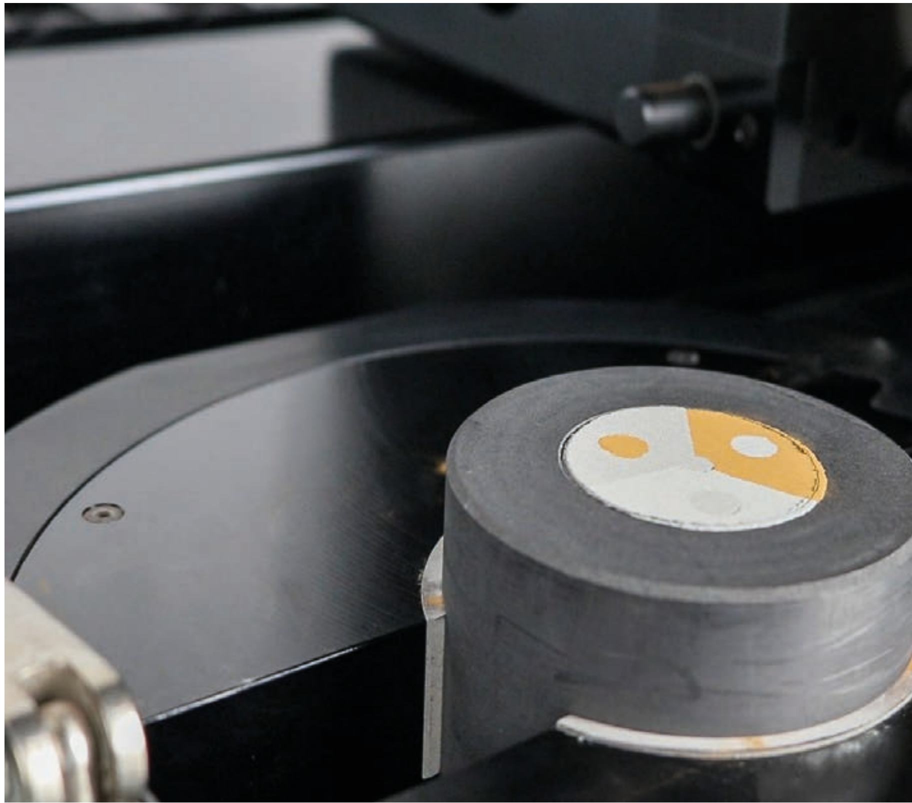
Once integrated in a binder jetting printer, the recoater is working with up to three different powders simultaneously. The multi-ceramic recoater is proposed as an option to ceramic binder jetting systems and allows the printers to precisely deposit multiple ceramic powders from a single layer. The powder layer deposited can then be processed with Desktop Metal binders to be sintered afterward. Multi-ceramic powder processing enables combining different types of ceramics and optimizing material properties in a binder jetting process.

The powder processing device proposed as an option to a Desktop Metal Ceramic System unlocks new possibilities for ceramic printing like color grading, powder gradients, near net shaping and much more.

Binder Jet Sintering Process

- Up to three different types of ceramic powders are deposited on the powder bed simultaneously following a precise pattern
- Binder is added to the powder bed after each layer
- The process repeats layer after layer to allow 3D print with multiple ceramics

▲ *Multi-Material Recoater*



▶ *Exemplary 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
- Energy
- Electronics
- Medical
- 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 the ORNL to develop a now commercialized, patent-pending method of 3D printing aluminum-infiltrated boron carbide (B4C) 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 a metal binder jetting system.*

▶ *Pictured above are Bianca Haberl (left) and Amy Elliott, both of ORNL, with parts printed in aluminum-infiltrated boron carbide (B4C). 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.

Evaluation of part for binder jetting

- Design & Geometry
- Metallurgy
- 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.

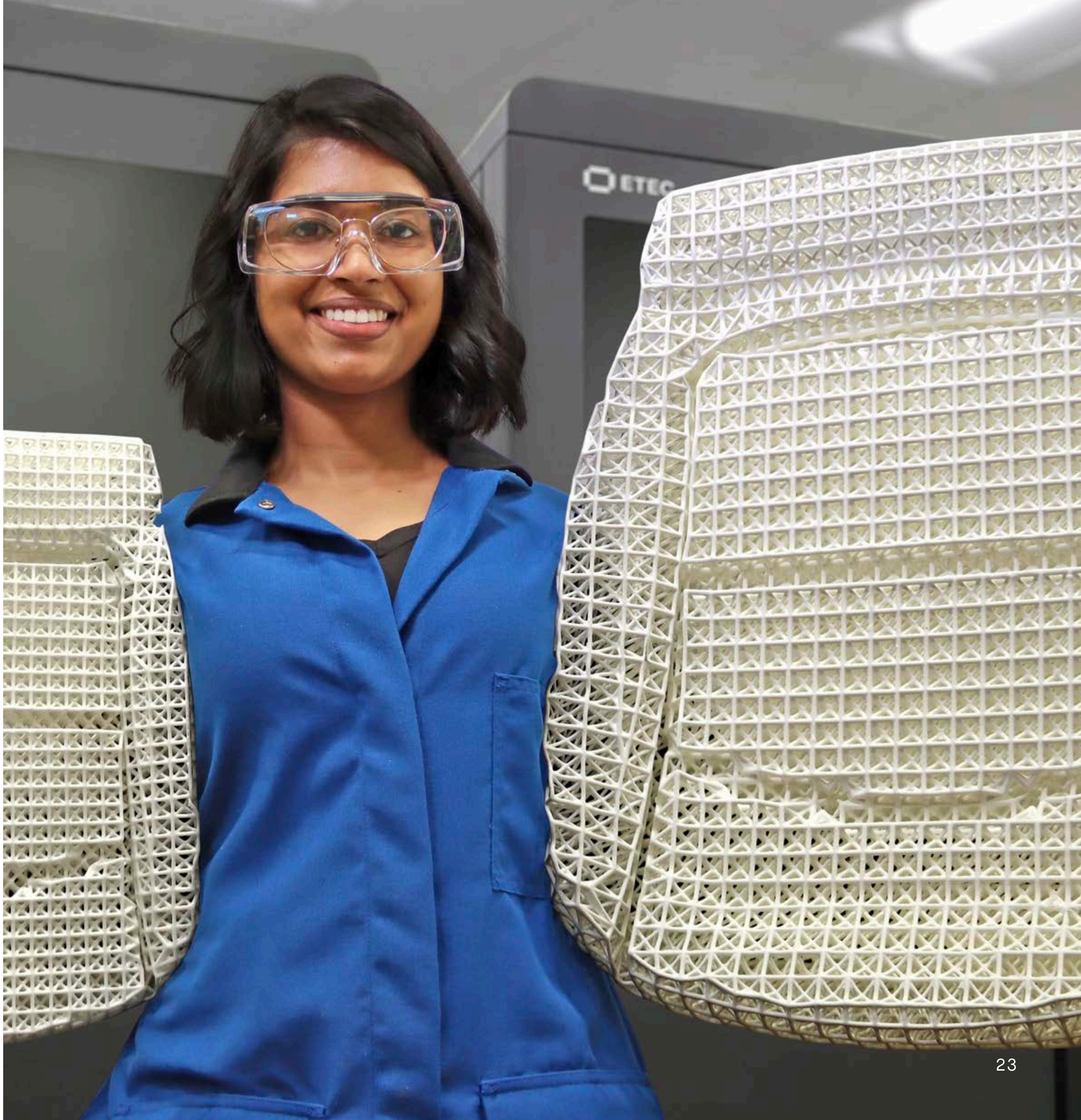
When it comes to ceramics, which are often used for the most advanced technology applications, we recommend engaging with our most knowledgable ceram experts on your project.

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.

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

#TeamDM



Desktop Metal

Pictured above, employees of Ultra Safe Nuclear Corporation with a Desktop Metal X160Pro being used for Silicon Carbide production used in USNC's Fully Ceramic Micro-encapsulated (FCM) fuel. The manufacturing of FCM is enabled by Desktop Metal binder jet 3D printers and their ability to 3D print silicon carbide heat-resistant ceramicparticles 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