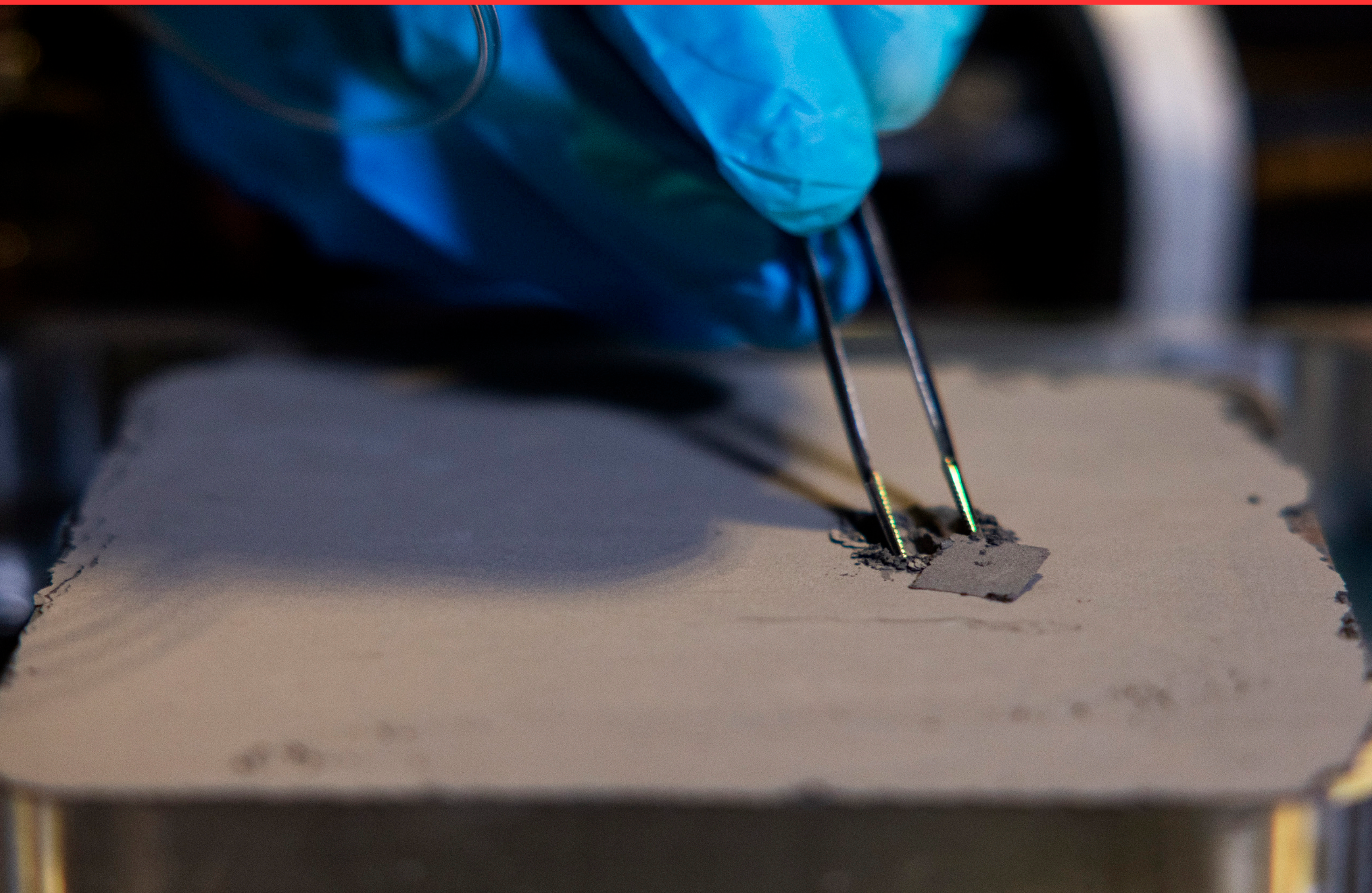
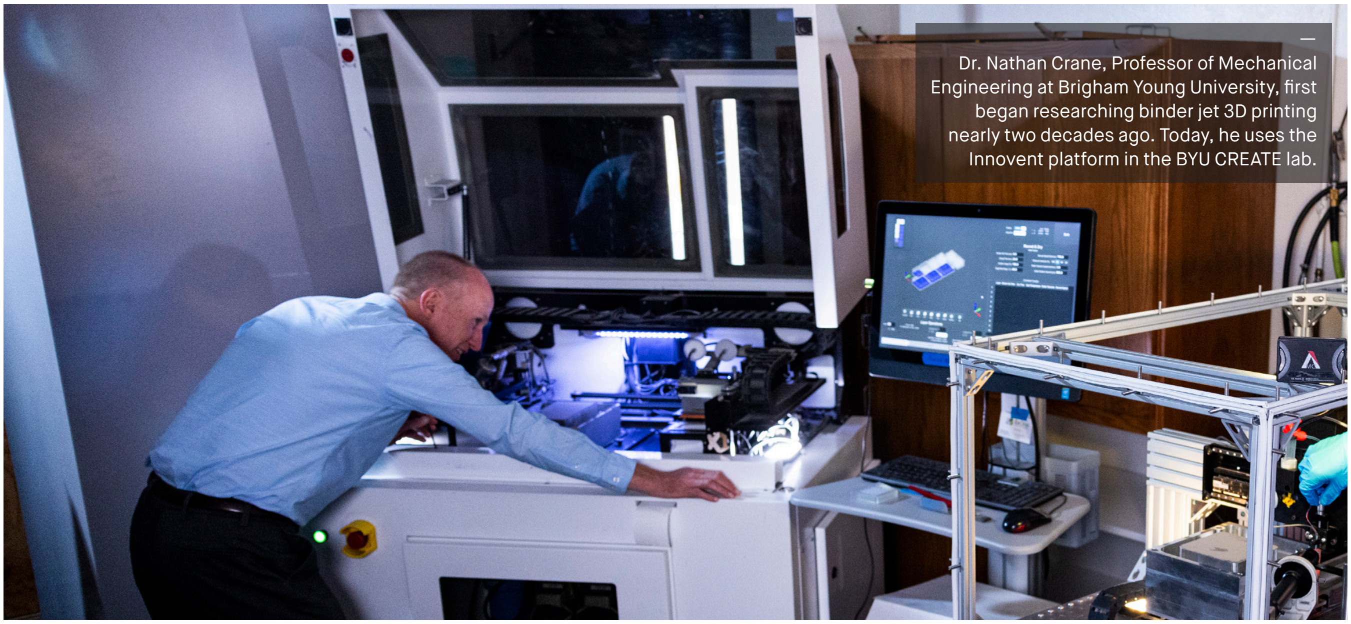
CASE STUDY

A Flexible, Accessible Metal 3D Printing Research Tool

Brigham Young University's CREATE Lab uses the Innovent to understand the fundamentals of the binder jetting process





Dr. Nathan Crane, Professor of Mechanical Engineering at Brigham Young University, first began researching binder jet 3D printing nearly two decades ago. Today, he uses the Innovent platform in the BYU CREATE lab.

Customer
CREATE Lab at
Brigham Young University

Location
Provo, Utah

Industry
Education and research

Application
Fundamental process research

Machine
Innovent

Website
www.am.byu.edu

Pioneering the study of powder and binder interactions

The binder jet additive manufacturing process is highly regarded for its ability to produce complex parts quickly and in a variety of materials without the need for a laser. Selectively binding layers of powder using inkjet printing technologies to create parts, binder jetting is used to advance applications in a range of industries such as tooling, automotive, and healthcare.

Dr. Nathan Crane, Professor of Mechanical Engineering at Brigham Young University, contributed to some of the earliest binder jetting development. Working under the inventor of the technology and Desktop Metal co-founder Ely Sachs, Dr. Crane wrote his 2005 Mechanical Engineering doctoral thesis at the Massachusetts Institute of Technology on the effect of nanoparticle dispersion on the reduction of sintering deformation and porosity of 3D printed parts[(1)].

In the two decades since, he has continued and expanded his research with government labs, as a Fulbright Scholar, and in academia.

As an Associate Professor at the University of South Florida, he led a research lab working on developing and improving advanced manufacturing and integration processes. In 2015, his lab at USF acquired an Innovent binder jetting system, which became a cornerstone in his research.

"Some of our early studies looked at how to separate final density from shrinkage so you could have varied density within the same part while maintaining compatible shrinkage," Dr. Crane explained. In these studies[(2)], the ability to change process variables on the Innovent, such as powder dispensing intervals, allowed his research team to fine-tune experiments.

In 2018, Dr. Crane joined the faculty at Brigham Young, returning to the institution where he earned his B.S. and M.S. degrees in Mechanical Engineering. Recognizing how the research-friendly Innovent helped advance the understanding of the binder jetting process, he acquired another Innovent machine for the CREATE Lab at BYU.

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>
> **Dr. Nathan Crane, Professor of Mechanical Engineering, Brigham Young University**

Understanding the boundaries of binder jet

Access to cutting-edge equipment at universities enables extensive research opportunities that can drive a technology’s progression. The CREATE Lab focuses on applying material science, mechanical design, and processing science to advance the adoption of manufacturing technologies such as 3D printing. Mechanical engineering students at the BYU lab have access to two powder-based metal additive manufacturing processes, powder bed fusion and binder jetting.

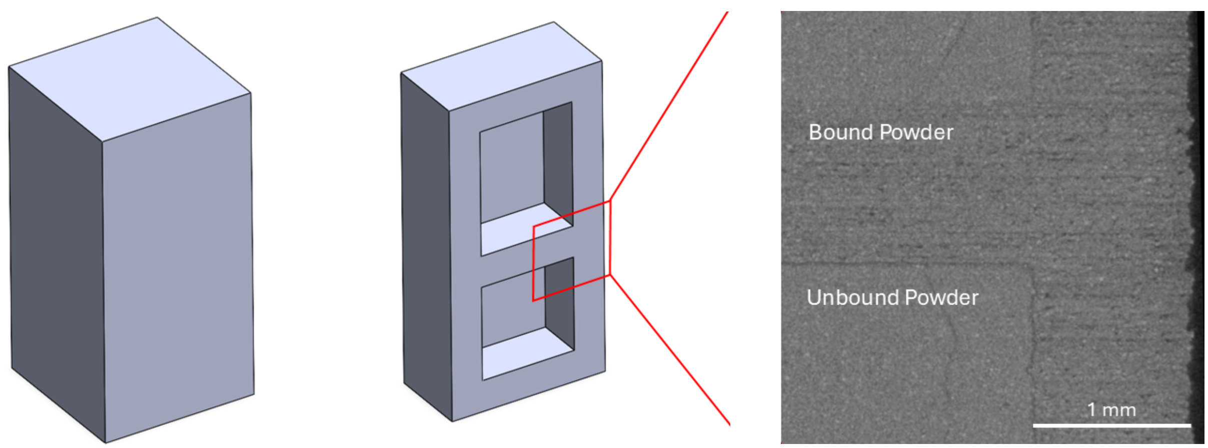
Binder jetting stands out for its quick builds and material versatility, as well as economical and user-friendly operation compared to laser powder bed fusion (L-PBF). Dr. Crane’s binder jetting work focuses on understanding the fundamental aspects of the laser-free additive process, including powder spreading and droplet deposition, which are essential to achieving high-quality printed parts.

While many research labs are dedicated to new material development or post-processing optimization, the team at BYU studies the printing process itself in steps like the spreading of the powder layers. “We‘re looking at understanding the process and bringing some innovations to how the process works,” Dr. Crane explained. “One thing we‘ve been studying is adding tiny amounts of moisture to the powder using a mist,” he continued. “We can apply that to the bed and look at the impact that has on the defect formation and printing windows. We‘re interested in understanding the fundamentals of the interactions and then exploring how the process might be adjusted to improve the results.”

The team has also investigated how drying impacts the capillarity of the binder to show how it impacts accuracy of parts, as well as focusing on what's happening when droplets of binder hit the powder bed. These studies have led to a nuanced understanding of density variations, shrinkage management, and powder drying processes – key areas for advancing binder jetting technology in industrial applications.

The open architecture of the Innovent has proven ideal for the CREATE Lab to achieve these goals. "It gives us enough flexibility to tailor our research," Dr. Crane said. "The nice thing about the Innovent is that we have enough control to simulate a broader range of conditions." He even admits the system allows him to do "more than the programmers planned for us to do," including adding some nonstandard attachments to test different configurations and evaluations.

To study correlations and replicate scaling of the technology, the team also uses a self-constructed experimental binder jetting machine from a custom motion system with an inkjet system. With full control over the one nozzle apparatus, the team prints single layers and basic shapes to study parameters such binder droplet velocity or size.



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Typically printing parts one centimeter or less in size, like the sample CAD model seen left, the team uses micro-CT to investigate the structure of the parts and sources of any voids. The section view, center, highlights the trapped powder region and the micro-CT image, right, looks at the structure of the parts around regions of trapped powder so the research team can compare as-spread to printed powders.

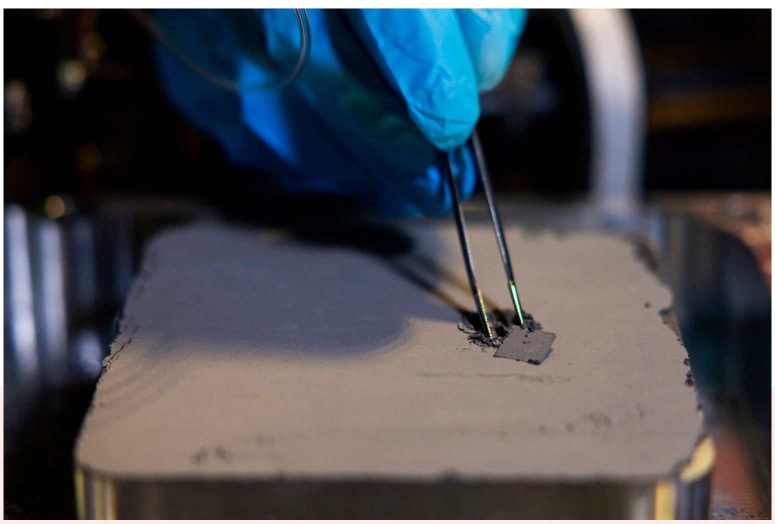
"We mostly do simple geometries on our experimental system and more complex geometries on the Innovent, and look for correlations," Dr. Crane said. He explained, "For example, we have been using our Innovent to look at spatial density variations with micro-CT and how it varies and is impacted by process parameters. These observations help us develop hypotheses that we can test on our custom apparatus with individual droplet interactions of printing just single lines. As we compare observations between the two platforms, we tease out key factors and identify new approaches."

Versatile research tool and accessible educational platform

The Innovent, the platform with the most published research[3], mainly serves as a research tool at BYU. However, its approachable workflow also enables it to support the academic curriculum as an educational platform.

The machine is run by undergraduate student operators who gain practical experience and support the research work of graduate students. Yet the turnover of students with the academic calendar doesn't negatively impact the lab's consistent results. "It's easy to train students to run compared to the laser powder bed fusion system," Dr. Crane explained. "Laser is much harder to keep a trained student on and to get good results compared to the binder jetting system. Students maybe get an average length of time of a year using the Innovent, but we've had good success."

A class on Design for Additive Manufacturing (DfAM) also benefits from the ease of use and low operational cost of the Innovent. "We like to have students design parts and it's affordable enough to run a batch and have the students depowder them and get a feel for the process and issues around designing and sintering," the professor said, explaining how the accessibility of the Innovent leads to higher throughput in the lab than the laser-based technology. "More students get to work with binder jetting because it's easier to train on and lower cost to operate."



The system also fosters cross-departmental collaboration, as Dr. Crane explained a joint project with the physics department investigating if metal additive manufacturing could enable higher complexity microfluidic

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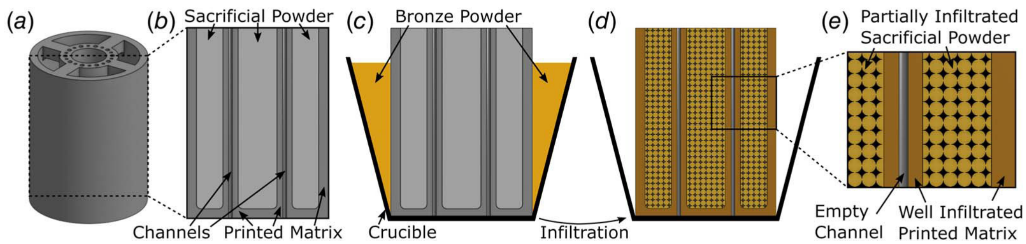
designs. The lab uses binder jetting to print complex structures as multiple pieces and rather than sinter the stainless steel, it is infiltrated using bronze to act as a braze to join the separate pieces. "It's a challenging niche application," he said, since the bronze infiltrant must fill the porous metal powder shape produced with binder jetting without filling the formed microchannels[4]. "The studying of the conditions under which you can fully infiltrate and seal everything without filling these fine channels that are as small as 250 microns is really interesting."



An illustration of the sacrificial powder infiltration process from a research paper[4] published by the team working with the Innovent binder jetting platform at Brigham Young University.

Many students continue their careers in sinter-based additive technologies after graduating, expanding the use of binder jetting in the field with an appreciation for what the technology can and cannot achieve. "It's been interesting to see it go from trying to be a solution for everything to identifying the applications where it really plays a role with a clear value add," Dr. Crane stated, highlighting successes with binder jet sandcasting molds or 3D printed metal to replace traditional tooling for low-volume injection molding production.

As binder jet additive manufacturing continues to evolve, research institutions like the CREATE Lab at Brigham Young University are crucial to driving innovation and expanding the boundaries of what the technology can achieve. "And with students' lab experience and improved understanding of the process, they are getting more accurate results so that binder jetting becomes more accessible to more manufacturers and hopefully keeps growing," Dr. Crane concluded.

Research example from the Innovent

Dr. Crane contributes to the improving quality of metal binder jetting through studies on powder behavior, droplet impacts on powder beds, and material density. The following overview is taken from one of many published research articles on topics including binder jetting, laser powder bed fusion, and electrowetting.

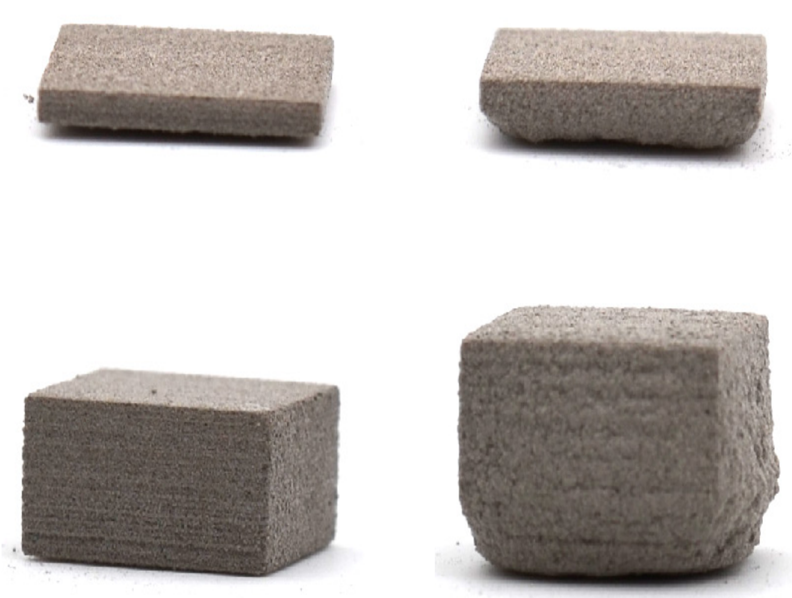
Impact of Part Thickness and Drying Conditions on Saturation Limits in Binder Jet Additive Manufacturing[5]

Growth in binder jetting applications is driven by the use of finer powders and improved post-processing methods that can produce dense, homogenous final parts. However, understanding of the basic droplet/powder interaction is relatively limited. This paper considers the impact of in-process drying, part geometry, and droplet size on a key printing parameter: binder saturation. Parts of varying thicknesses are printed on the Innovent with a range of saturation levels under various heating conditions. The ratio of the printed part mass to the theoretical part mass is used to detect bleeding. In unheated powder beds, part mass increases linearly with printing saturation levels across the range tested (30%-130%).

However, when the powder is heated between layers, there is a wide range of print saturation levels (¬30-80%) over which increasing binder saturation or droplet volume does not increase the part mass. This stable part mass corresponds to accurate part geometry without bleeding and is likely due to enhanced evaporation of the binder solvent between layers.

Smaller droplet volume (42 pl) was also shown to decrease saturation levels in unheated powder bed and in single layer parts. The differences in part mass with print saturation and droplet volume are most pronounced in thin parts.

These observations lead to a simple method for determining an appropriate print saturation parameter for a powder/binder combination in thick parts.



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Samples printed on the Innovent to compare the impact of in-process drying by way of a heated printbed on a key printing parameter, binder saturation. The samples seen left above were printed with a heated bed, and those seen right unheated, and 1mm and 5mm thicknesses respectively.

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Refereces

(1) Strengthening porous metal skeletons by metal deposition from a nanoparticle dispersion. Nathan B Crane - Massachusetts Institute of Technology Department of Mechanical Engineering – 2005 https://dspace.mit.edu/handle/1721.1/32385

(2) Binder-Jet Printing of Fine Stainless Steel Powder With Varied Final Density. Mohsen Ziaee , Eric. M. Tridas , and Nathan B Crane - Journal of Materials, v 69, n 3, p 592-596 - March 1, 2017 https://scholarsarchive.byu.edu/cgi/viewcontent.cgi?article=6251&context=facpub

(3) https://www.sciencedirect.com/search?qs=binder%20jet%20and%20innovent

(4) Sacrificial Powder Pressure Control for Infiltration of Microscale Printed Metal Parts. Henry D. Davis, James G. Harkness, Isa M. Kohls, Nathan Crane, Brian D. Jensen, Richard Vanfleet, Robert C Davis - ASME. J. Manuf. Sci. Eng. May 2024; 146(5): 051002. https://doi.org/10.1115/1.4064628

(5) Impact of Part Thickness and Drying Conditions on Saturation Limits in Binder Jet Additive Manufacturing. Nathan B. Crane - Additive Manufacturing, Vol 33, May 2020, Article 101127 doi.org/ 10.1016/j.addma.2020.101127

BYU
BRIGHAM YOUNG UNIVERSITY

About the Brigham Young University CREATE Research Lab

The CREATE Lab, part of the Mechanical Engineering department in the College of Engineering at Brigham Young University, researches the manufacturing of systems of the future. The CREATE lab combines advances from diverse fields to enable the manufacturing processes of tomorrow with applications ranging from microscale actuation to thermal control and building construction.

Desktop Metal.

About Desktop Metal Inc.

Desktop Metal (NYSE:DM) is driving Additive Manufacturing 2.0, a new era of on-demand, digital mass production of industrial, medical, and consumer products. Our innovative 3D printers, materials, and software deliver the speed, cost, and part quality required for this transformation. We're the original inventors and world leaders of the 3D printing methods we believe will empower this shift, binder jetting and digital light processing. Today, our systems print metal, polymer, sand and other ceramics, as well as foam and recycled wood. Manufacturers use our technology worldwide to save time and money, reduce waste, increase flexibility, and produce designs that solve the world's toughest problems and enable once-impossible innovations. Learn more about Desktop Metal and our #TeamDM brands at www.desktopmetal.com