Bursting your (tiny) bubbles: new research points the way toward pore-free 3-D printing

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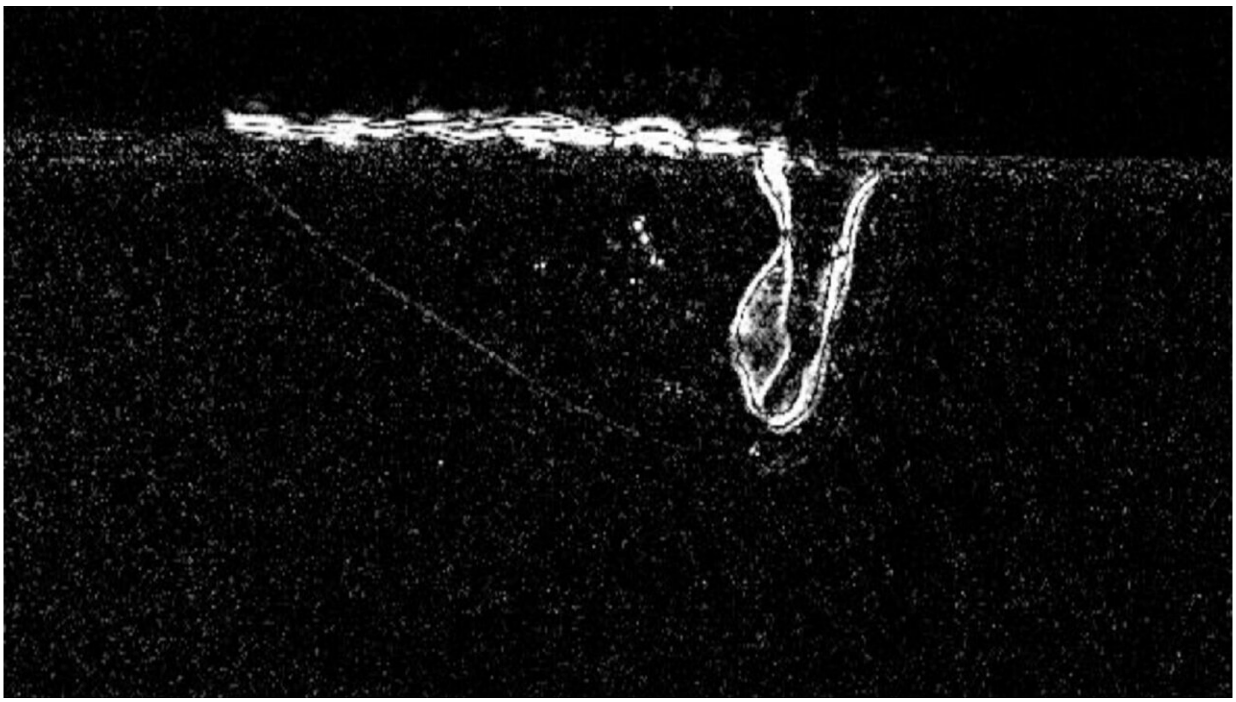

This X-ray image captured at the APS shows a laser melting aluminum during the additive manufacturing process. To the left of the laser you can see tiny pores created during the process, which can over time create defects in the finished product. Credit: Tao Sun

New research conducted at the Advanced Photon Source (APS) shows that 3-D printing of metal components without the pores that weaken their structural integrity is not only possible, but would need no additional devices to realize.

Additive manufacturing's big advantage is the convenience of fabricating geometrically complex parts. Need to quickly design and build a new engine component for an airplane? Fire up the 3-D printer and make one. But with that convenience often comes a drawback: 3-D-printed parts are not as durable as those crafted through traditional manufacturing processes, and won't hold up under repeated stresses over time.

A team of scientists may now have the answer to that problem. Even better, their pivotal discovery does not require redesigning and updating 3-D-printing machines. Researchers say it can be done with the technology we already have.

Additive manufacturing, commonly called 3-D printing, has been a reality for nearly 40 years. This process transforms computer models of, well, anything into fully realized 3-D structures made of plastics, metals or other materials. As part of the process, however, [microscopic pores](https://phys.org/tags/microscopic+pores/) find their way into the finished product, weakening the structural integrity. Eliminating these pores from 3-D-printed metal parts is key to advancing the technology into more useful applications.

As any scientist will tell you, the first step toward fixing a problem is to get a good look at what is causing it. Researchers have been using the Advanced Photon Source (APS), a U.S. Department of Energy (DOE) Office of Science User Facility located at DOE's Argonne National Laboratory, to study the additive manufacturing process since 2015. The APS generates intensely bright X-rays, which can penetrate into the metal parts, taking images as the metal is shaped from powder in real time.

"The APS provides a way of seeing things that we couldn't before," said

Kamel Fezzaa, a physicist in Argonne's X-ray Science division, who oversees the high-speed imaging program at APS beamline 32-ID-B. "Instead of using static samples after the printing is complete, we are able to see inside the process as it happens."

That process is called laser powder bed fusion, and it involves using high-power lasers to melt and fuse powdered material together. Using a laser-and-powder setup at the APS, a team of researchers documented the formation and subsequent movement of pores—many smaller than the width of a human hair—within the melt pool. The team was led by Lianyi Chen, formerly of the Missouri University of Science and Technology and now of the University of Wisconsin-Madison, and Tao Sun, formerly of Argonne's X-ray Science division and now of the University of Virginia.

The APS allowed them to capture 135,776 images per second, each image lasting for less than a microsecond, and the result was the most detailed look at the additive manufacturing process ever seen.

"The APS has the best capability of doing this type of study," said Sun. "It would be impossible to do this at a lab-based X-ray source. We're probing a highly dynamic process, and the APS offers us nanosecond-level time resolution."

What this research team found surprised even them. In a paper published in *Nature Communications*, the group described the three forces acting upon pores within the melt pool: buoyancy, which should force the gas up and out of the melt area; melt flow drag, which should swirl the gas around within the molten pool; and thermocapillary force, which drives the pores to move along the temperature gradient.

Of these three forces, they discovered that the thermocapillary force in certain area of the molten pool exerts the most influence over where the pores ended up. The drag created by the melting liquid metal is second, which means that the natural tendency of these gas pockets to move upward and out of the melt area was countered.

"We did not expect these results," Chen said. "As the laser strikes the material, the pores move out of the melt pool rapidly in the laser interaction area."

The team found that it is the temperature gradient induced thermocapillary force that drags the pores out, Chen explained, so simply exerting more control over the temperature gradient during the 3-D-printing process itself can move those pores outside the melt area, ensuring that the resulting metal part is pore-free.

"This is not a force that people thought about before," Sun said. "But we can utilize this force to remove all of the pores in a printed component."

Making use of this technique, researchers say, should be possible with existing 3-D-printing equipment. Controlling the power and speed of the laser, and adjusting for different types of material, should allow manufacturers to find the right conditions to shape the thermal force as the laser is doing its work.

It would take some trial and error, Fezzaa said, but it should not require an additional device to eliminate pores from the finished product.

"This is a proof of concept," Fezzaa said. "One of the main challenges in 3-D printing is to make it as reliable as traditional manufacturing, and if this concept could be used as an effective tool in a real 3-D system, that would be a giant leap forward for the additive manufacturing industry."

More information: S. Mohammad H. Hojjatzadeh et al. Pore elimination mechanisms during 3D printing of metals, *Nature*

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