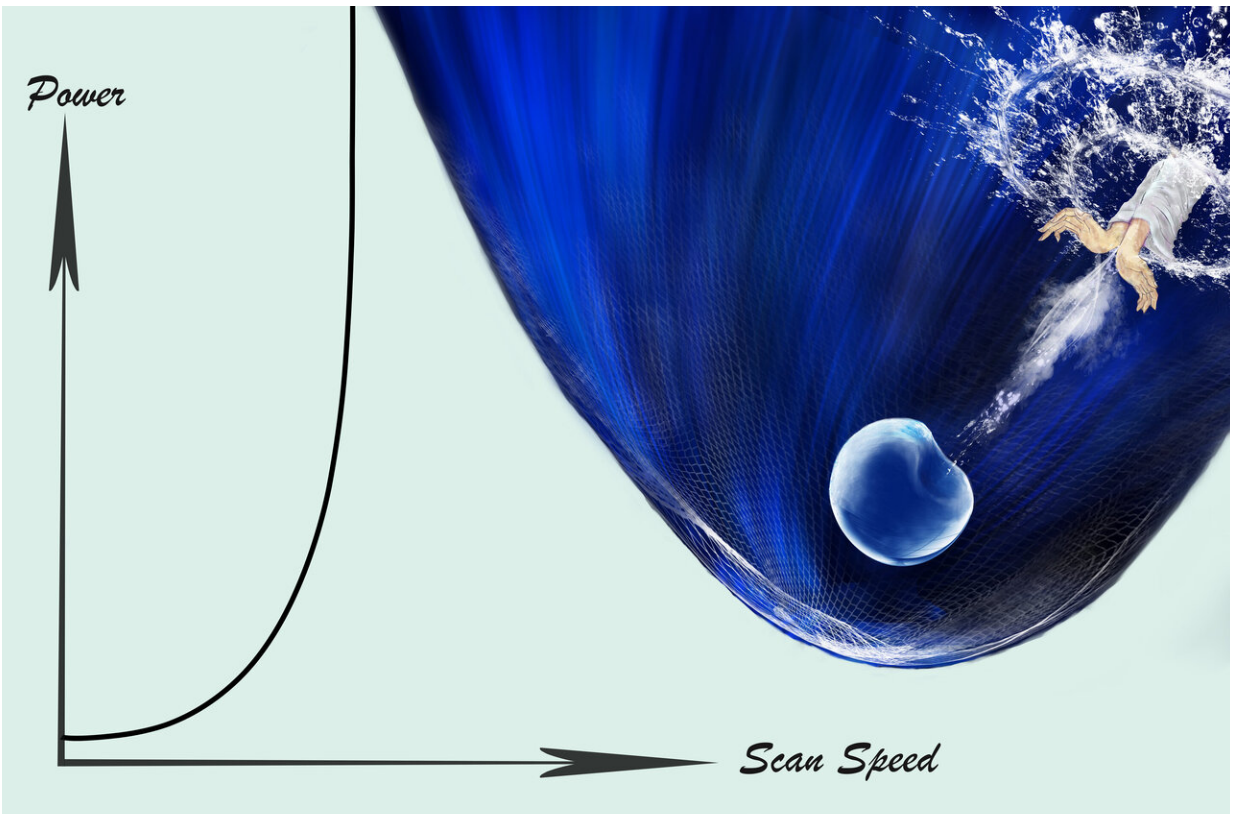
A route for avoiding defects during additive manufacturing

November 26 2020



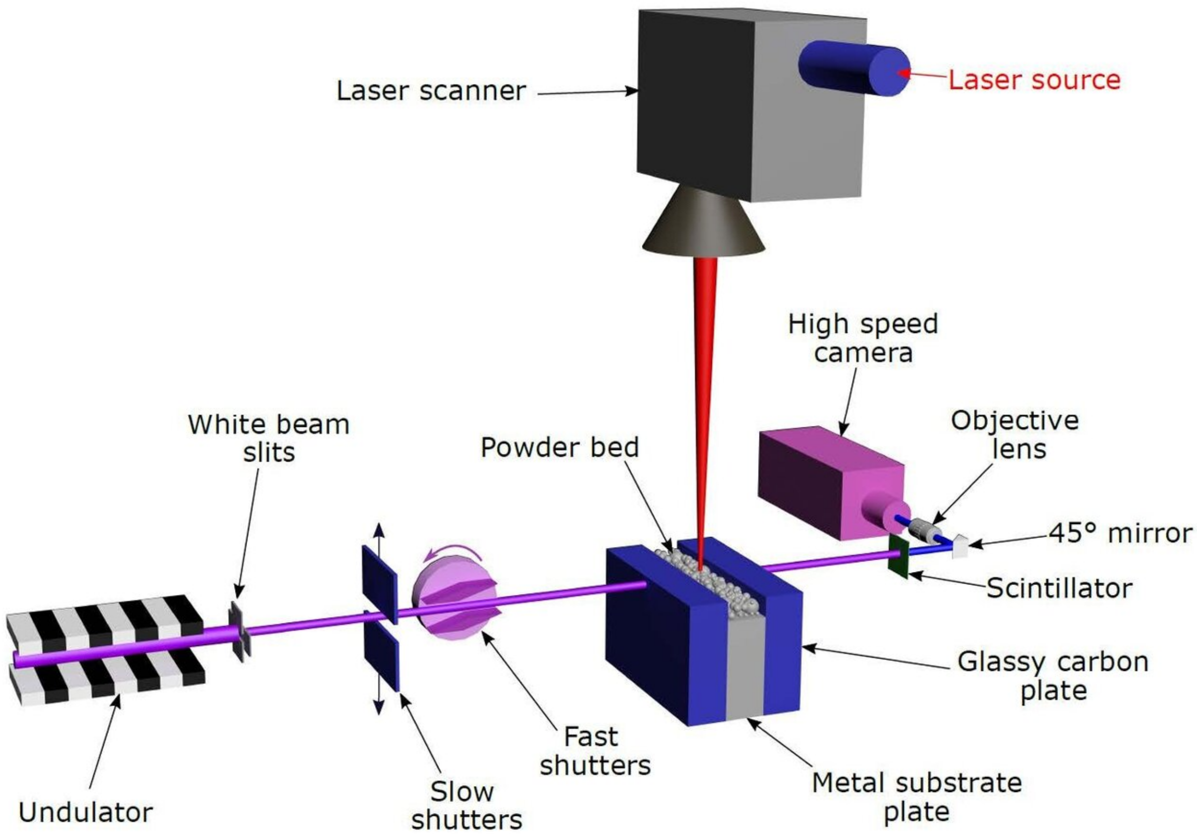
Artwork showing the boundary and origin of keyhole porosity. On the left side of the figure, the keyhole porosity boundary in the laser power – scan velocity space is sharp and smooth. On the right side, around the porosity boundary, the critical keyhole instability releases acoustic waves (shock waves) in the melt pool. The waves then drive the pore near the keyhole tip to accelerate rapidly away from the keyhole. When the pore is captured by the solidification front, it becomes a detrimental structural defect in the build. Credit: Ye Feng, Cang Zhao at Tsinghua University

Laser powder bed fusion is a dominant additive manufacturing technology that has yet to reach its potential. The problem facing industry is that tiny bubbles or pores sometimes form during the printing process, and these pores create weak spots in finished products.

When a slow-speed, high-power laser is melting metal powder during the 3-D printing of a part, a keyhole-shaped cavity in the melt pool can result. Pores, i.e. defects, form at the bottom of the keyhole. New research published in *Science* reveals how the pores are generated and become defects trapped in solidifying metal.

"The real practical value of this research is that we can be precise about controlling the machines to avoid this problem," says Anthony D. Rollett, a professor of materials science and engineering in Carnegie Mellon College of Engineering and a lead co-author of the paper, "Critical instability at moving keyhole tip generates porosity in laser melting."

Building on previous research that quantified the keyhole phenomenon, the research team used extremely bright high-energy X-ray imagining to watch instabilities of the keyhole. Pores form during fluctuations of the keyhole, and it changes its shape: the keyhole tip morphs into a "J" shape and pinches off. This unstable behavior generates acoustic waves in the liquid metal that force the pores away from the keyhole so that they survive long enough to get trapped in the resolidifying metal. The team is the first to focus on this behavior and identify what is happening.



Schematic of operando synchrotron x-ray experiment on laser powder bed fusion (LPBF), with x-ray optics to control the beam, sample holder with glassy carbon plates to contain powder, scintillator to convert x-rays to light, high-speed camera to capture movies and high-power laser with scan head to deliver a laser beam to melt the surface of the sample. Credit: Carnegie Mellon University College of Engineering

"When you have a deep keyhole, the walls oscillate strongly. Occasionally, the oscillations are strong enough at the bottom of the keyhole that they pinch off, leaving a large bubble behind. Sometimes this bubble never reconnects to the main keyhole. It collapses and generates an acoustic shock wave. This pushes the remaining pores away from the keyhole," explains Rollett.

It's important to note that keyholes themselves are not flaws and, e.g., they increase the efficiency of the laser. Using synchrotron X-ray equipment at Argonne National Laboratories, the only facility in the United States where the researchers could run these experiments, they noted that there is a well-defined boundary between stable versus unstable keyholes.

"As long as you stay out of the danger zone [i.e., too hot, too slow], the risk of leaving defects behind is quite small," says Rollett.

Fluctuations in the keyhole's depth increase strongly with decreasing scan speed and laser power on the unstable side of the boundary.

"You can think of the boundary as a speed limit, except it is the opposite of driving a car. In this case, it gets more dangerous as you go slower. If you're below the speed limit, then you are almost certainly generating a defect," adds Rollett.

At a broader scale, by proving the existence of well-defined keyhole porosity boundaries and demonstrating the ability to reproduce them, science can offer a more secure basis for predicting and improving printing processes. Rollett, who is the faculty co-director of Carnegie Mellon's Next Manufacturing Center, thinks that the findings from this research will quickly find their way into how companies operate their 3-D printers.

More information: C. Zhao at Tsinghua University in Beijing, China el al., "Critical instability at moving keyhole tip generates porosity in laser melting," *Science* (2020). science.sciencemag.org/cgi/doi … 1126/science.abd1587

Provided by Carnegie Mellon University