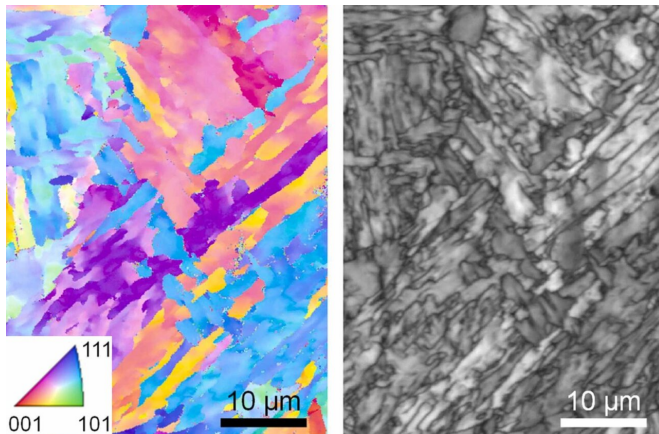


Researchers uncover how to 3D-print one of the strongest stainless steels

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A microscopic image of 3D-printed 17-4 stainless steel. The colors in the left-side version of the image represent the differing orientations of crystals within the alloy. Credit: NIST

For airliners, cargo ships, nuclear power plants and other critical technologies, strength and durability are essential. This is why many contain a remarkably strong and corrosion-resistant alloy called 17-4 precipitation hardening (PH) stainless steel. Now, for the first time ever, 17-4 PH steel can be consistently 3D-printed while retaining its favorable characteristics.

A team of researchers from the National Institute of Standards and Technology (NIST), the University of Wisconsin-Madison and Argonne National Laboratory have identified particular 17-4 steel compositions that, when printed, match the properties of the conventionally manufactured version. The researchers' strategy, described in the journal *Additive Manufacturing*, is based on high-speed data about the [printing process](#) they obtained using high-energy X-rays from a particle accelerator.

The new findings could help producers of 17-4 PH

parts use 3D printing to cut costs and increase their manufacturing flexibility. The approach used to examine the material in this study may also set the table for a better understanding of how to print other types of materials and predict their properties and performance.

Despite its advantages over conventional manufacturing, 3D-printing of some materials can produce results that are too inconsistent for certain applications. Printing metal is particularly complex, in part because of how quickly temperatures shift during the process.

"When you think about additive manufacturing of metals, we are essentially welding millions of tiny, powdered particles into one piece with a high-powered source such as a laser, melting them into a liquid and cooling them into a solid," said NIST physicist Fan Zhang, a study co-author. "But the cooling rate is high, sometimes higher than one million degrees Celsius per second, and this extreme nonequilibrium condition creates a set of extraordinary measurement challenges."

Because the material heats and cools so hastily, the arrangement, or [crystal structure](#), of the atoms within the material shifts rapidly and is difficult to pin down, Zhang said. Without understanding what is happening to the crystal structure of steel as it is printed, researchers have struggled for years to 3D-print 17-4 PH, in which the crystal structure must be just right—a type called martensite—for the material to exhibit its highly sought-after properties.

The authors of the new study aimed to shed light on what happens during the fast temperature changes and find a way to drive the internal structure toward martensite.

Just as a high-speed camera is needed to see a hummingbird's flapping wings, the researchers needed special equipment to observe rapid shifts in structure that occur in milliseconds. They found the

right tool for the job in synchrotron X-ray diffraction, or XRD.

"In XRD, X-rays interact with a material and will form a signal that is like a fingerprint corresponding to the material's specific crystal structure," said Lianyi Chen, a professor of mechanical engineering at UW-Madison and study co-author.

At the Advanced Photon Source (APS), an 1,100-meter-long [particle accelerator](#) housed at Argonne National Lab, the authors smashed high-energy X-rays into steel samples during printing.

The authors mapped out how the crystal structure changed over the course of a print, revealing how certain factors they had control over—such as the composition of the powdered metal—influenced the process throughout.

While iron is the primary component of 17-4 PH steel, the composition of the alloy can contain differing amounts of up to a dozen different chemical elements. The authors, now equipped with a clear picture of the structural dynamics during printing as a guide, were able to fine-tune the makeup of the steel to find a set of compositions including just iron, nickel, copper, niobium and chromium that did the trick.

"Composition control is truly the key to 3D-printing alloys. By controlling the composition, we are able to control how it solidifies. We also showed that, over a wide range of cooling rates, say between 1,000 and 10 million degrees Celsius per second, our compositions consistently result in fully martensitic 17-4 PH steel," Zhang said.

As a bonus, some compositions resulted in the formation of strength-inducing nanoparticles that, with the traditional method, require the steel to be cooled and then reheated. In other words, 3D printing could allow manufacturers to skip a step that requires special equipment, additional time and production cost.

Mechanical testing showed that the 3D-printed steel, with its martensite structure and strength-inducing nanoparticles, matched the strength of steel produced through conventional means.

The new study could make a splash beyond 17-4 PH [steel](#) as well. Not only could the XRD-based approach be used to optimize other alloys for 3D printing, but the information it reveals could be useful for building and testing computer models meant to predict the quality of printed parts.

"Our 17-4 is reliable and reproduceable, which lowers the barrier for commercial use. If they follow this composition, manufacturers should be able to print out 17-4 structures that are just as good as conventionally manufactured parts," Chen said.

More information: Qilin Guo et al, Phase transformation dynamics guided alloy development for additive manufacturing, *Additive Manufacturing* (2022). [DOI: 10.1016/j.addma.2022.103068](https://doi.org/10.1016/j.addma.2022.103068)

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