New superalloy could cut carbon emissions from power plants

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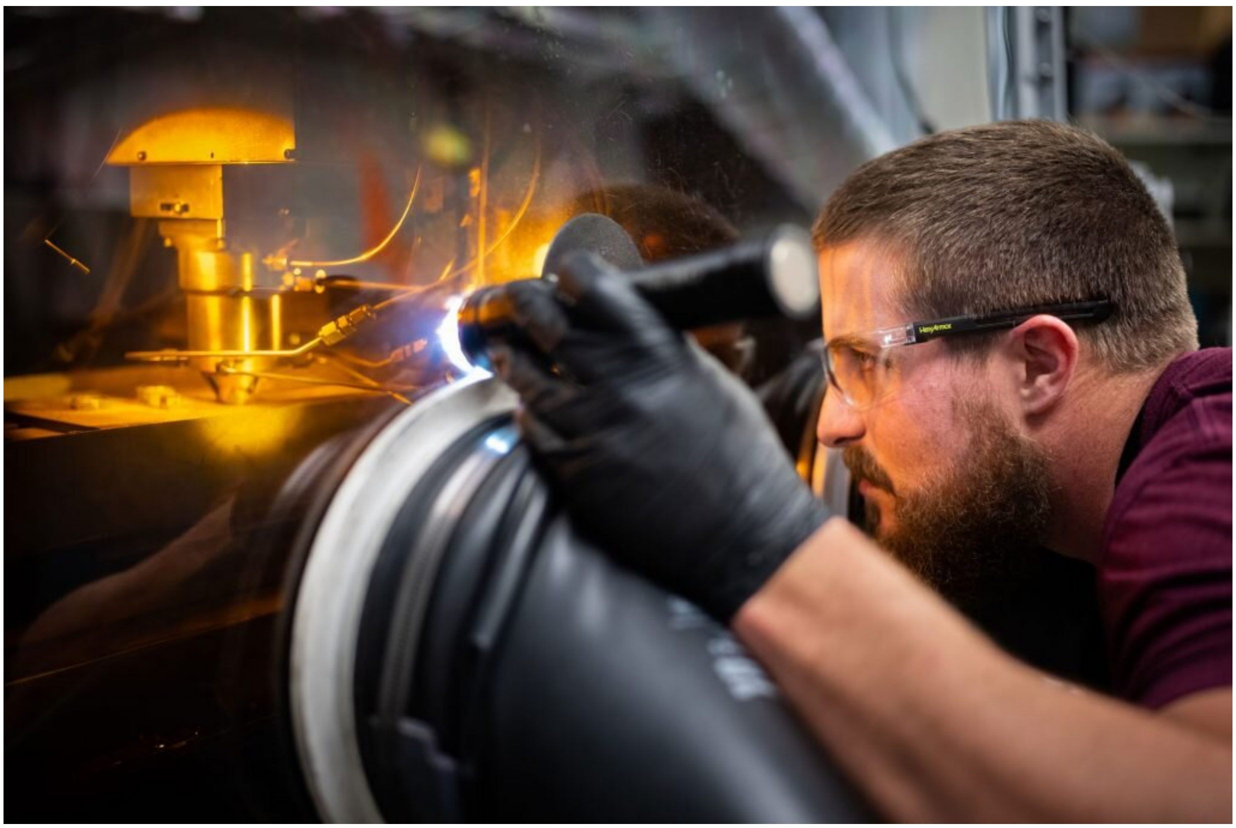

Sandia technologist Levi Van Bastian works to print material on the Laser Engineered Net Shaping machine, which allows scientists to 3D print new superalloys. Credit: Craig Fritz

As the world looks for ways to cut greenhouse gas emissions, researchers from Sandia National Laboratories have shown that a new 3D-printed superalloy could help power plants generate more electricity while producing less carbon.

Sandia scientists, collaborating with researchers at Ames National Laboratory, Iowa State University and Bruker Corp., have used a 3D printer to create a high-performance metal alloy, (superalloy), with an unusual composition that makes it stronger and lighter than state-of-the-art materials currently used in gas turbine machinery. The findings could have broad impacts across the energy sector as well as the aerospace and automotive industries, and hint at a new class of similar alloys waiting to be discovered.

"We're showing that this material can access previously unobtainable combinations of high strength, low weight and high-temperature resiliency," Sandia scientist Andrew Kustas said. "We think part of the reason we achieved this is because of the additive manufacturing approach."

The team published their findings in the journal *Applied Materials Today*.

Material withstands high heat, essential for power plant turbines

About 80% of electricity in the U.S. comes from fossil fuel or nuclear power plants, according to the U.S. Energy Information Administration. Both types of facilities rely on heat to turn turbines that generate electricity. Power plant efficiency is limited by how hot metal turbine parts can get. If turbines can operate at higher temperatures, "then more energy can be converted to electricity while reducing the amount of waste heat released to the environment," said Sal Rodriguez, a Sandia nuclear engineer who did not participate in the research.

Sandia's experiments showed that the new superalloy—42% aluminum, 25% titanium, 13% niobium, 8% zirconium, 8% molybdenum and 4% tantalum—was stronger at 800 degrees Celsius (1,472 degrees Fahrenheit) than many other high-performance alloys, including those currently used in turbine parts, and still stronger when it was brought back down to room temperature.

"This is therefore a win-win for more economical energy and for the environment," Rodriguez said.

Energy is not the only industry that could benefit from the findings. Aerospace researchers seek out lightweight materials that stay strong in high heat. Additionally, Ames Lab scientist Nic Argibay said Ames and Sandia are partnering with industry to explore how alloys like this could be used in the automotive industry.

"Electronic structure theory led by Ames Lab was able to provide an understanding of the atomic origins of these useful properties, and we are now in the process of optimizing this new class of alloys to address manufacturing and scalability challenges," Argibay said.

Discovery highlights changes in materials science

Additive manufacturing, also called 3D printing, is known as a versatile and energy-efficient manufacturing method. A common printing technique uses a high-power laser to flash-melt a material, usually a plastic or a metal. The printer then deposits that material in layers, building an object as the molten material rapidly cools and solidifies.

But this new research demonstrates how the technology also can be repurposed as a fast, efficient way to craft new materials. Sandia team members used a 3D printer to quickly melt together powdered metals and then immediately print a sample of the mixture.

Sandia's creation also represents a fundamental shift in alloy development because no single metal makes up more than half the material. By comparison, steel is about 98% iron combined with carbon, among other elements.

"Iron and a pinch of carbon changed the world," Andrew said. "We have a lot of examples of where we have combined two or three elements to make a useful engineering alloy. Now, we're starting to go into four or five or beyond within a single material. And that's when it really starts to get interesting and challenging from materials science and metallurgical perspectives."

Scalability and cost are challenges to overcome

Moving forward, the team is interested in exploring whether advanced computer modeling techniques could help researchers discover more members of what could be a new class of high-performance, additive manufacturing-forward superalloys.

"These are extremely complex mixtures," said Sandia scientist Michael Chandross, an expert in atomic-scale computer modeling who was not directly involved in the study. "All these metals interact at the microscopic—even the atomic—level, and it's those interactions that really determine how strong a metal is, how malleable it is, what its melting point will be and so forth. Our model takes a lot of the guesswork out of metallurgy because it can calculate all that and enable us to predict the performance of a new material before we fabricate it."

Andrew said there are challenges ahead. For one, it could be difficult to produce the new superalloy in large volumes without microscopic cracks, which is a general challenge in additive manufacturing. He also said the materials that go into the alloy are expensive. So, the alloy might not be appropriate in consumer goods for which keeping cost down is a primary concern.

"With all those caveats, if this is scalable and we can make a bulk part out of this, it's a game changer," Andrew said.

More information: Andrew B. Kustas et al, Extreme hardness at high temperature with a lightweight additively manufactured multi-principal element superalloy, *Applied Materials Today* (2022). DOI: 10.1016/j.apmt.2022.101669

Provided by Sandia National Laboratories

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