Army strong: Research teams join forces to invent weld wire for tank, infrastructure repair

December 13 2022, by Dawn M Levy

Oak Ridge National Laboratory materials scientist Zhili Feng, left, looks on as senior technician Doug Kyle operates a welding robot inside a robotic welding cell. Credit: Carlos Jones/ORNL, U.S. Dept. of Energy

The U.S. Departments of Energy and Defense teamed up to create a series of weld filler materials that could dramatically improve high-strength steel repair in vehicles, bridges and pipelines. This novel weld wire could help revitalize America's aging infrastructures, which in 2021 received a C- grade from the American Society of Civil Engineers.

The invention from DOE's Oak Ridge National Laboratory and the U.S. Army enables onsite welding without costly, laborious heat treatments typically used to reduce residual stresses and material distortion. It solves a major problem of welded steels that occurs when hydrogen atoms enter the metal during welding and reduce the metal's ductility, toughness and strength. Subsequently, high tensile residual stress leads to perilous cracking.

"The filler material that ORNL and the U.S. Army invented is a unique and game-changing solution for residual stress control, distortion reduction and avoidance of hydrogen-induced cracking for a wide range of structural steels," said Zhili Feng, who leads ORNL's Materials Joining Group. He heads research and development programs to advance materials joining and manufacturing for automotive, nuclear energy, fossil energy, hydrogen and defense technologies.

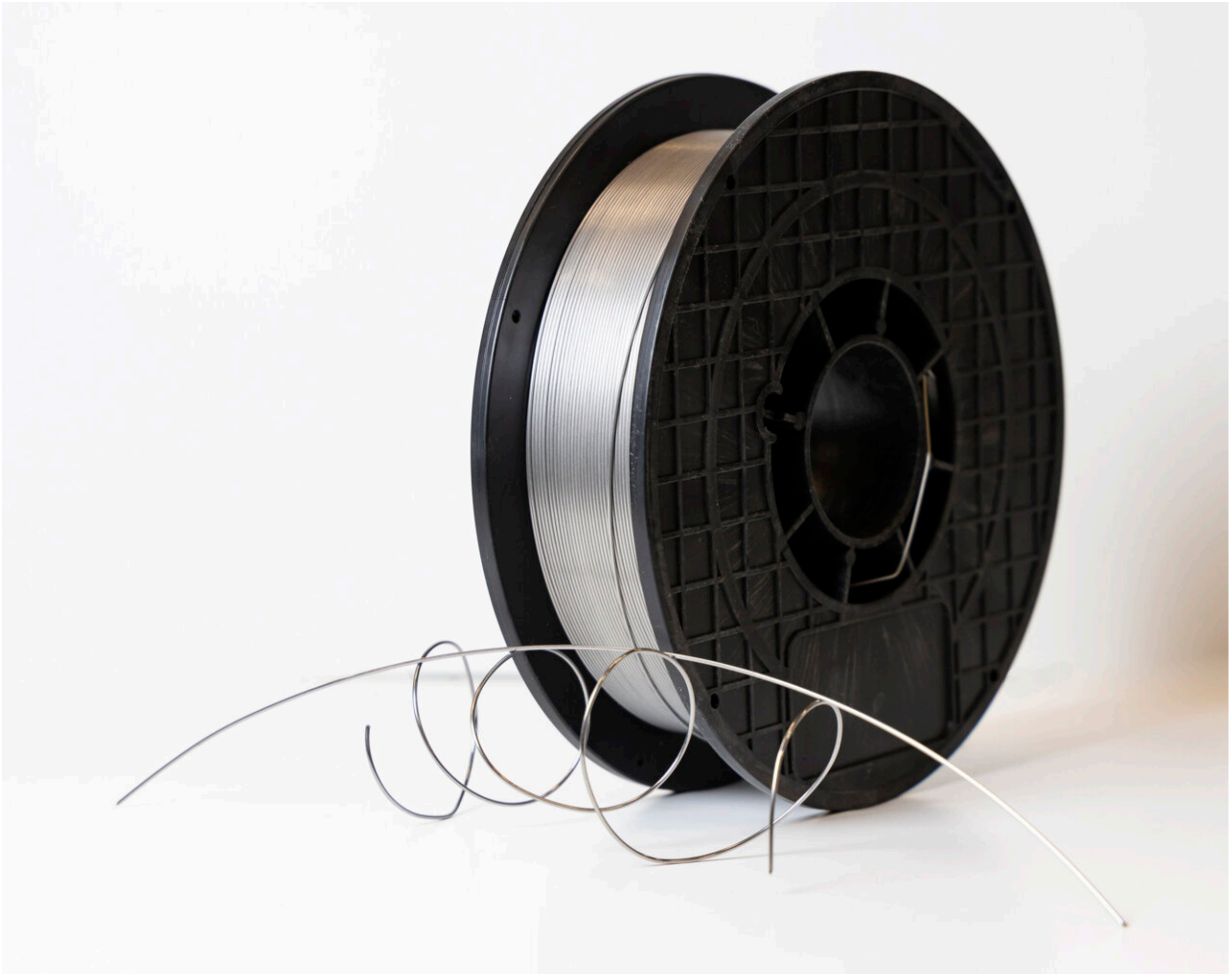
"About 80% of welded structures in the United States are made of steels, so applications for our innovative fill metal are extensive," said Stan David, an ORNL corporate fellow emeritus who led the lab's welding program for 25 years before retiring. "It is cheaper to repair a structure than to replace it. Our filler provides high-quality weld joints for increased service life of welded structures in demanding environments. The invention could potentially save U.S. industry hundreds of millions to billions of dollars each year."

If stronger steel is used to make a welded structure, then less of it is needed, reducing weight, saving energy and cutting carbon dioxide emissions during materials manufacturing and vehicle operation. That results in more fuel-efficient cars, lighter-weight combat and support vehicles, and more durable fuel pipelines. However, strong steels are especially prone to hydrogen-induced cracking.

To overcome this challenge, scientists at ORNL and DOD's former U.S. Army Tank Automotive Research, Development and Engineering Center—now called the Ground Vehicle System Center—partnered to invent an alloy with a unique chemical composition that can join strong steels while reducing residual stresses.

The alloy's ability to resist hydrogen-induced cracking comes from a novel phase transformation in the weld. As a weld cools, the filler material combats tensile stress, or "bad stress," which pulls at steel's crystalline microstructure to lengthen and break it. The phase transformation introduces compressive stress, or "good stress," to compensate for bad stresses as the weld cools.

No part of a welded structure is exposed to more stress than the weld region, where metal is heated and expands, then cools and contracts. Long after thermal expansion and contraction are over, stress remains in the material to distort it, creating the structure's weakest link.



Interagency success came full circle: A DOE-funded project to make weld wire for cars attracted DOD investment to trailblaze technology for tanks. That spurred other DOE investments. Credit: Carlos Jones/ORNL, U.S. Dept. of Energy

A weld filler needs to be at least as strong as the steel panels it joins. To develop the chemical composition of their pioneering, stress-compensating filler, ORNL researchers ran a theory-based model on high-performance computers. With more efficient algorithms, the computing code ran a thousand times faster than a comparable commercial code, identifying problems in one day versus nearly three years.

The inventors used this process to arrive at a filler that works with structural steels of varying strengths and alloy compositions. Characterization of welded materials with neutron diffraction at the High Flux Isotope Reactor and the Spallation Neutron Source, DOE Office of Science user facilities at ORNL, showed remarkable reductions in residual stresses.

Interagency success story

This interagency success story began in 2011, when DOE's Office of Energy Efficiency and Renewable Energy's Vehicle Technologies Office funded ORNL scientists to work with multinational steel manufacturer ArcelorMittal on a cooperative R&D agreement. Automakers had begun using stronger steels to fabricate thin panels that reduced vehicle weight. However, thinner panels meant increased stress on the welds. The automakers soon found that the welds in strong steels required enhanced fatigue resistance to combat the increased stresses. ORNL's novel weld wire provided the solution they needed.

In high-strength steels, the root cause of hydrogen embrittlement and metal fatigue is the same—residual stress. Wanting to reduce the weight of military tanks with ultrastrong armor to improve agility and fuel efficiency, the Army approached ORNL in 2013 to exchange information about what to do to solve hydrogen-induced cracking of armored steel components.

"We turned to ORNL because its welding research is world-class, and the partnership gave us access to the best-in-class experts and instrumentation of a national lab," said Demetrios Tzelepis, a senior materials engineer at the Army vehicle system center. "ORNL kept pushing the research envelope, and together we delivered a superb solution."

Feng added, "The requirements for tank steel and automotive steel are very different. ORNL had to change the chemistry of our weld wire to match the steel strength for the Army's applications." The resulting technology won an R&D 100 Award in 2017.

In 2018, the Army and ORNL teamed up again to explore welding of next-generation steels. Work is ongoing to improve and refine the weld wire alloy they originally developed for tomorrow's ultrastrong, lightweight armor.

And more recently, the Army and ORNL teamed up one more time to extend the weld wire for large area metal additive manufacturing. The weld wire may offer very high strength and toughness in bulk structures while at the same time dramatically lowering distortion and residual stresses.

Yiyu Wang, a scientist in Feng's group, tests and characterizes materials to determine how welding affects microstructure. His work proves the weld wire lowers stresses. Credit: Carlos Jones/ORNL, U.S. Dept. of Energy

From vehicles to pipelines

The weld wire whose chemical composition was initially developed to repair cars and later evolved to fix tanks has since progressed to mend pipelines and other critical infrastructures. The DOE Hydrogen Program, led by EERE's Hydrogen and Fuel Cell Technologies Office, conducts research and development in areas including hydrogen delivery, infrastructure and storage. In 2016, the program ramped up efforts addressing challenges to pipelines transporting gaseous hydrogen both alone and mixed with natural gas. It also explored challenges to high-pressure vessels for storing liquid hydrogen.

Feng's team worked to further refine the wire for pipeline steels, which have different chemical compositions and strengths compared to steels for cars and military tanks. In 2019, DOE's Fossil Energy and Carbon Management Office began looking into extending the lives of millions of miles of aging oil and gas pipelines with this newest weld wire through various repairs that minimize hydrogen-induced cracking and avoid expensive and time-consuming preheating and post-weld heat treatment.

Moreover, the novel weld wire may also prove useful in additive manufacturing, or 3D printing, which employs localized melting to add layers one at a time and can create profound stresses in a fabricated part. The Army and ORNL again teamed up to explore the ability of innovative materials to avoid distortion and increase strength in printed steel parts.

"Huge economic benefits could come from eliminating cracking and post-fabrication distortion in welded or 3D-printed steel structures," Feng said.

The researchers have applied for a patent of their novel weld wire.

Provided by Oak Ridge National Laboratory

Citation: Army strong: Research teams join forces to invent weld wire for tank, infrastructure repair (2022, December 13) retrieved 23 April 2024 from https://techxplore.com/news/2022-12-army-strong-teams-weld-wire.html