Neutron Diffraction Finds Hidden Stresses in Materials Critical for Safety, Energy, and the Environment

Metalsa, EPRI, and John Deere are among the partners in these high-impact studies.

WHETHER IT'S THAT KLUNKY NEW HUMMER YOU BOUGHT FOR A SONG, THAT HONEY OF A BMW sports coupe, farm equipment from John Deere, or a pressurized water nuclear reactor, the materials from which they are made contain hidden stresses that affect safety, longevity, even energy efficiency and the environment.

Camden Hubbard and his Residual Stress User Center at the ORNL High Temperature Materials Laboratory (HTML) use the second-generation Neutron Residual Stress Facility (NRSF-2) at HFIR, along with complementary x-ray diffraction instrumentation, to help industrial partners find out where these stresses are. Their input corrects or validates the companies' computational models so that they ultimately can make better, safer, less costly, and more efficient structural materials.

In another project of importance to the country's 100+ pressurized water reactors (PWRs), the team works with the Electrical Power Research Institute (EPRI) and the Nuclear Regulatory Commission (NRC) to detect stresses in the welds on pipes that conduct coolant water from reactor vessels.

Residual stresses are innate to materials. When industry makes a vehicle, the materials are subjected to heat, shot blasting, or laser blasting, as manufacturers modify them to get improved performance and corrosion resistance. "They're always playing with the process to change the residual stresses to minimize the detrimental stress state and maximize the beneficial," Hubbard explains.

When the metal components in a vehicle are welded together, and the vehicle hits the road for several hundred thousand miles, further stresses occur. Such stresses can be either detrimental—opening up the material and contributing to crack formation—or beneficial, compressive stresses that push the materials closer together, making parts last longer.

Today, manufacturers use computer modeling to try to predict the processes within materials. Working with materials scientists at ORNL, they use NSRF-2 to validate their models. "They want to see if their models are making the right predictions so that they can then use the models with more confidence," Hubbard says.

The actual science entails neutron diffraction, bringing a beam of thermal neutrons to diffract off the sample material. At HFIR, a monochromater selects one energy of neutrons to feed through the beam. "When you know the energy and you can see at what angle the neutrons are scattered, you can measure the interplanar spacing, or d-spacing, of the atoms in the materials," Hubbard explains.

The changes in the material may be 100 parts per million, Hubbard says, so this is one of the more precise measurements done with neutron instruments at ORNL.

Three projects currently running at HFIR involve industrial partnerships with Metalsa S. de R.L. (car and truck chassis frames, suspension mod-

Matt Klug from Dominion Engineering, a subcontractor to EPRI, uses NSRF-2 to study stress distributions in joints welded to PWRs, helping to project crack growth and the probability of failure in the welds.

The Neutron Residual Stress Facility maps hidden stresses that affect the performance of materials.

ules, structural stampings, and truck side rails), EPRI and the NRC (PWRs), and John Deere (farm and forestry equipment).

Metalsa makes 50% of the steel frames for trucks and SUVs in North America. The frame is the unifying base of the vehicle to which everything is attached. As a vehicle travels, there are flexing stresses, and the manufacturer wants to know what effect boring holes in the frame to attach components will have on residual stresses in the material.

The team's results could result in saving expensive raw materials and improving fuel efficiency, saving as much as 200 lb per truck.

The collaboration with EPRI and the NRC concerns ongoing questions about joints that are welded to the country's PWRs. In PWRs, the coolant water exits the reactor vessel, typically a carbonized steel, via a large stainless steel pipe that is welded to the vessel wall with a weld called a "dissimilar metal weld."

In their inspections of PWR plants, EPRI and the NRC have discovered that the weld is one of the places where problems occur. The residual stresses at the joint can either close cracks and keep them from breaking, or open cracks faster. The researchers used neutrons to look for the stress distributions so they can project crack growth and the probability of failure. The project is also examining methods that could be used to reduce the probability of cracking and thus improve safety and the operational life of the reactor.

The third project, with industrial partner John Deere, involves stresses in cast materials. When metal is melted and poured into a die, it cools differently at different locations, which sets up residual stresses in the casting.

"They need to be able to predict these stresses to ultimately predict proper performance of the part. So they bring us several parts with different casting operations to see if their computer models for die casting are giving the right answers," says Hubbard.

"We did neutron residual stress measurements on several of these, and it turns out the data predictions from the models and the measurements that we had were pretty good—as good as I ever expected they could be."

Confident that they have it right, John Deere can look at how to optimize the casting, at what temperature, at what speed to do the cooling, now that the computer simulations have been validated by neutron experiments at HFIR.

"This is a big-impact study," Hubbard says. Castings are heavily used throughout all transportation industries, even in jet planes.

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