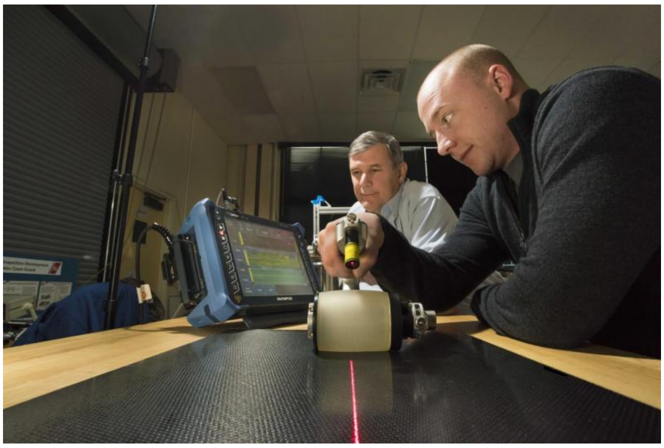
Nondestructive techniques to detect damage in composites

2 February 2016, by Sue Holmes



andia National Laboratories technologist Andrew Lentfer passes a roller probe over a composite as researcher David Moore checks data on a screen. The nondestructive testing technique sends sound waves into the composite material, returning data with each swipe of the roller probe. Credit: Randy Montoya

Researcher David Moore holds a rectangle of hard carbon composite material, smooth with a faint woven pattern on its surface. The sample shows normal wear and tear until he turns it over to reveal a circular impact mark with cracks radiating from it.

The question for Moore, his Sandia National Laboratories colleague Timothy Briggs in California and their teams is whether the impact caused significant, hidden damage inside the composite. They're developing nondestructive ways to detect damage in composites, using traditional medical inspection techniques such as X-rays and sonograms and advanced methods including infrared imaging, ultrasonic spectroscopy and computed tomography.

Sandia began studying composites several years ago to see whether the lightweight materials could be used in national security applications. While a composite in a cell phone needs to last only a couple of years, "typically materials for national security applications must survive for decades. This makes you think differently about where and why you would use a material," said Moore, who works in the Structural Dynamics and X-ray/Nondestructive Evaluation department. "We need to study the lifecycle of a component. We tend to think deeply about the consequences of fracture or deformation and how we can verify what happened."

The work supports many aspects of Sandia's national security mission, including energy efficiency and performance improvements in lightweight vehicles or wind turbine blades, said Briggs of Sandia California's Lightweight Structures organization.

Composites join together separate materials with different characteristics. They often consist of a soft polymer matrix with reinforcing fibers like carbon, Kevlar or glass. Composites can use bundles of thinner-than-a-hair carbon strands that yield a high strength-to-weight ratio. The final shape and strength is obtained after heating the part in an industrial oven that sets the polymer resin and yields the qualities necessary for a structural component.

Composites are increasingly important in aerospace and other industries because they're strong and weigh less than metals. Most can be bonded to metal for such uses as aircraft wings, making planes lighter and less expensive to fly.

Outside surface of a composite doesn't hint at what's inside

"We have a rich history of understanding metals and their failure mechanisms," Moore said. "Composite materials are very different."

If a service truck backs into a composite aircraft fuselage, an examination of the impact site might not detect damage under the surface. That highlights the reason for nondestructive techniques that can fully evaluate how composites react in various circumstances.

The research team is assessing the accuracy of nondestructive methods and how they could be used on a production floor. "You have to know what could go wrong in the processing steps and how to circumvent those, and then you want to make sure if you're going to make one or a hundred or a thousand that you're making them the same way all the time," Moore said.

"Once we establish the limits of detectability, the threshold of good, bad and questionable, we'll be able to say, 'We want this composite bonded to this material with a defined quality and it shall be inspected with this technique,'" he said.

Sandia's Lightweight Structures Lab defines and consolidates materials to study, using particular stack sequences of composite material layers to tailor strength and stiffness. It works in concert with the National Security Campus in Kansas City, Missouri, in everything from developing process methods to building prototypes to qualifying designs for particular applications.

After making composites, the fabrication lab cuts out specimens for instrumented experiments—abusing the carefully made sample to study deformation, fracture and damage growth. Briggs "pulls, stretches, torques and crushes them. He performs these mechanical experiments so we can understand the fracture mechanisms around failure," Moore said. "Then we try to detect some of those failure modes."

Characterizing material properties helps computer modeling, simulation

"The fundamental characterization of composites measures material properties and structural characteristics, which in turn provides information to validate computer modeling and simulation," Briggs said.

Data from these destructive tests is correlated with nondestructive evaluations from Moore's team to understand what caused the material to respond the way it did, Briggs said. The effort hinges on close collaboration with Sandia's materials characterization groups and modeling and simulation colleagues to help validate their computer-based simulations.

Composites must support a particular weight and size. "Anyone can build a structure to carry the load, but we have to design our structures to fit within a geometric envelope and be lightweight," Briggs said. "We cannot simply over-engineer to unrealistic levels. We have to be very smart and efficient with our designs, yet provide enough margin for long-term reliability."

Materials bonded in an oven or autoclave often have different thermal expansion rates—aluminum expands more than fiber-reinforced plastics, for example. Once a composite cools after curing, residual stresses can build up inside, particularly at interfaces. If the composite can't handle those stresses, the bonds can fail.

Sandia is developing advanced techniques to complete sample inspections in less than 5 minutes in some cases. "This is a way to gain a lot of information very quickly about the quality of the bonds," Moore said.

Team studies specific nondestructive techniques

His team uses the deliberately mistreated composites to assess such inspection techniques as advanced ultrasonics, flashed or active thermography and computed tomography.

Ultrasonic testing has been around for 60 years, but computers and other improvements now allow study of more complex applications. Technologist Andrew Lentfer demonstrates, scanning a piece of composite with a handheld ultrasonic roller that resembles a small paint roller with a hollow, water-filled barrel. As he scans the composite's layers, a computer screen maps them in color: Yellow-green is OK; blue indicates weakness. Rollers can scan curved surfaces, even large ones like airplanes.

Fibers and interfaces in a composite scatter ultrasonic waves moving through the material. Moore compares it to ocean waves: "If a wave hits a rock face in the ocean it moves around it; if a wave washes up on the sand it gets absorbed; and if it hits a seawall the wave energy is redirected quickly. Those are the same fundamentals we investigate: ultrasonic energy moving through a composite matrix."

Knowledge gained from characterizing materials helps develop new nondestructive techniques "so when we establish an inspection criteria, we have a better feel for what we can detect and what we cannot," he said.

Flashed thermography, commercially available for more than 20 years, flashes very high-energy light onto a surface for 15 microseconds, then an infrared camera watches how the surface cools. The process takes only minutes.

"It's very fast, but you have to understand the fundamentals of heat flow and how the material surface either gives off heat to its surroundings or transfers heat within itself," Moore said.

Studies use good, not-so-good composites to test differences

The research uses composites with high-quality bonds and others deliberately made with weaker bonds. Differences in results help the team improve detection of defects or damage. A computer screen shows light or dark spots indicating possible problems, and an overlaid graph ties the depth of the potential problem to the time indicated on the image.

"The question becomes, is that a concern? Is that a crack or not?" Moore said. "We'll be able to answer those questions. If the defect propagates deep into the material, we may not detect it. It's wise to understand the capabilities of the technique and then perform the math and science behind it."

Computed tomography systems are efficient for finding small defects. The technique rotates a sample 360 degrees while taking 1,000 images, similar to a medical CT scan, and generates an image from each thin slice of the object. Since each image taken is two dimensional, computer algorithms reconstruct, calculate, locate and display everything to represent the object in three dimensions.

"Once the 3-D image is reconstructed, you look at the front surface and then start moving through the thickness to view what is below the surface," Moore said. "This technology gives us a knowledge baseline and validates how the other techniques are performing."

Sandia must ensure designs meet requirements by specifying and qualifying an inspection technique, and now is writing inspection procedures for the National Security Campus, Moore said. "Once we establish criteria and limits of acceptability, the product definition can be established," he said.

Provided by Sandia National Laboratories