New inspection process freezes parts in ice

May 1 2019, by Brandon Pytel

University of Cincinnati professor Francesco Simonetti holds up a manufactured part encased in ice. The ice works as a coupling medium for ultrasonic inspection. Credit: Corrie Stookey/CEAS Marketing

"How on Earth did they make that?" asks Francesco Simonetti, commenting on an ice sculpture of a swan.

Simonetti isn't admiring the artistry of shaping a block of ice into a bird. He's admiring the swan's crystal-clear transparency.

Simonetti, an aerospace engineering professor at the University of Cincinnati, is an expert in sound waves, but lately he's been an apprentice in ice. And when it comes to sound waves, the clearer the ice, the better.

Simonetti recently published a novel approach that uses ultrasound to inspect additive-manufactured parts: He dips the part in water and freezes it inside a cylinder of ice. The ice acts as a coupling medium, letting ultrasonic waves enter and reflect against the part's potential defects.

To describe this grouping of ultrasound and ice, Simonetti coined the term cryoultrasonics. Cryoultrasonics can have a dramatic influence on industry, ensuring additive manufacturers build reliable parts.

The work appeared this month in *NDT& E International*, one of the leading journals in nondestructive testing and evaluation.

Problems surface

Simonetti uses cryoultrasonics to inspect safety-critical parts, like metal parts in jet engines or power plants. Because people's lives are at stake, engineers need to be able to detect any potential defects in these parts before they're used in practice.

In traditional subtractive manufacturing, ultrasound testing works just fine. A manufacturer starts with a solid block of material, which engineers can test for defects by sending ultrasonic waves through it.

But new technologies, like additive manufacturing, challenge this approach. Additive manufacturers build a desired part not by subtracting from a block but by adding layer on layer. Ultrasonic waves bounce off the angles and curves of these new parts, instead of the potential cracks or defects.

"Sound needs a coupling medium to propagate from a source transducer into the volume of a part," says Simonetti. "When the contrast in mechanical properties between the coupling medium and the part is large, very little energy enters, and it doesn't work."

Many people have tested water as a coupling medium. They immersed the part in water and sent ultrasound waves through it. Water's mechanical properties, however, are very different from metals. Very little ultrasonic energy can even make it to the part.

So Simonetti turned to ice.

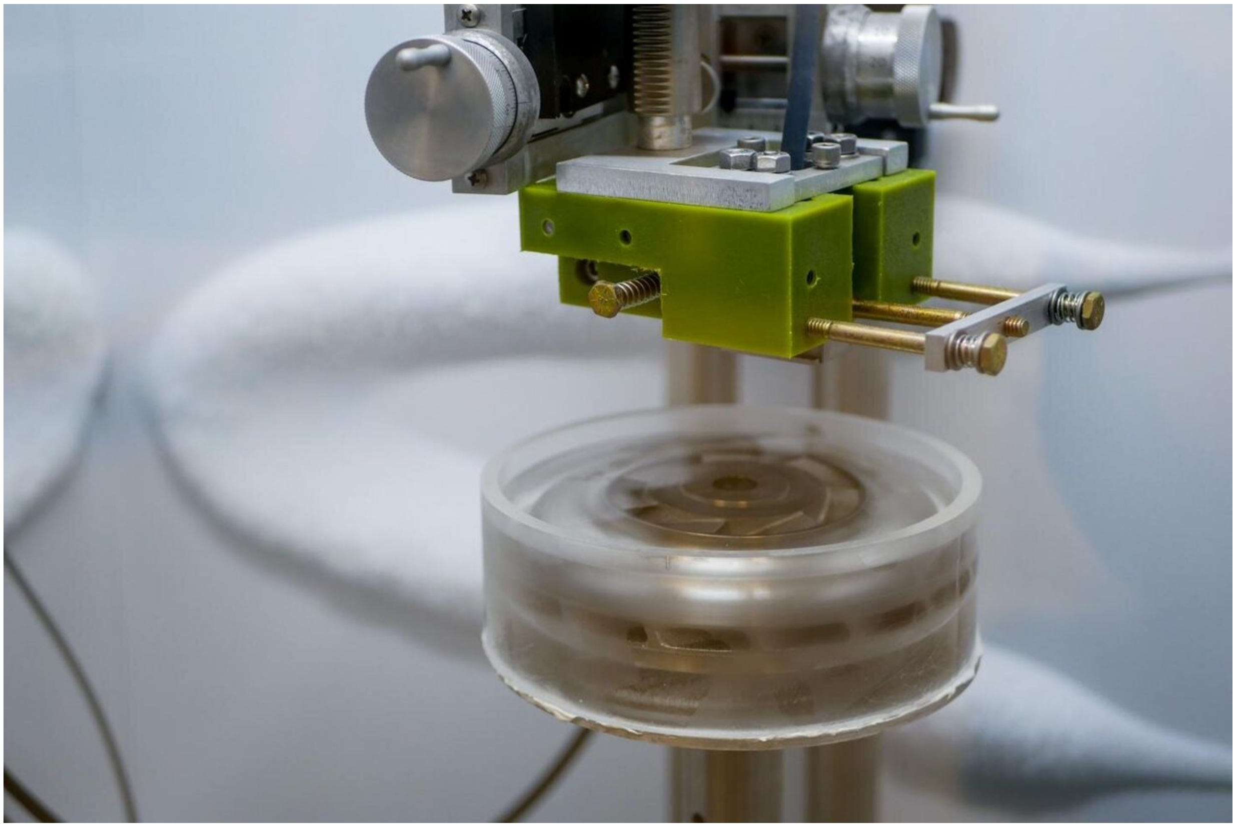
"Living in Cincinnati, you're always removing ice from the drive way. I got curious to see what the ice properties were," says Simonetti.

"We tried all the conventional techniques and nothing would work. At that point, we looked for desperate measures, and I just thought, 'Why don't we try?'"

Simonetti freezes the metal part in a cylinder of ice and then sends ultrasonic waves through it. Since the physical properties of ice are very similar to those of the metal part, the waves easily pass through the ice and encased metal and pick up any defects in the part. When he's done, the ice simply melts.

At least that's the idea.

"The first attempts were disastrous," says Simonetti.



University of Cincinnati professor Francesco Simonetti developed a novel approach to inspecting manufactured parts that requires freezes them in ice. Credit: Corrie Stookey/CEAS Marketing

For ice to act as an effective coupling medium, it has to be crystal clear—If any cracks or bubbles exist, ultrasound waves will reflect off of the defects in the ice rather than the defects in the part.

But ice isn't crystal clear. It's cloudy and fractured. Send an ultrasound wave through it and the wave bounces in 15 directions. It's even worse for bigger blocks of ice, like those needed to encase some of these metal parts.

Simonetti needed to find a way to freeze ice around the part while keeping the ice transparent. That meant getting a special machine that froze ice without causing bubbles or cracks.

"Of course, we had to build this thing," he says.

Simonetti made this custom ice machine by hand, combining things bought on Amazon like baking pans, griddles and spindles. It's like a science kitchen set, but it does the job. That job is to tackle the two obstacles that prevent the formation crystal-clear ice: cracks and bubbles.

Cracks form because water expands as it solidifies. Water freezes from the outside, forming a solid ice shell with liquid core. As the core solidifies, it tends to expand against the shell, which causes a buildup of internal forces that leads to cracking.

To prevent this cracking, Simonetti has made a cylinder with a metal base and plastic sides. Simonetti puts the metal part he's inspecting inside of the cylinder and fills it with water. He then chills the metal base, which causes the water to freeze from bottom to top. The water eventually solidifies around the metal part and expands to the open top of a cylinder, rather than the sides.

Bubbles are little trickier. Dissolved air exists in water. As water freezes, it expels the excess air. This excess air accumulates on the freeze front, or where the water is turning to ice, to form bubbles.

"In order to prevent this phenomenon, you need to simply reduce the concentration of air on top of the freeze front. To do that, we stir the water to have constant flow," says Simonetti.

To create this constant flow, Simonetti uses a spindle. By keeping the water in motion, the excess air never accumulates and the bubbles never form.

The result is a metal part encased by a block of crystal-clear ice, rivaling even the clearest ice sculpture. Simonetti can send ultrasonic waves unimpeded through this block to measure the safety of a metal part. When he's done, he simply puts the part under water and the ice melts right off.

Simonetti admits that ice is only one step forward in inspecting these critical-safety parts. Ice is a good coupling medium because it has similar properties to that of metal, but it's still not exact.

"Ideally, if the coupling medium were made of the same material as the part, it would be perfect," says Simonetti. "But that is not practical with something like liquid titanium. Experimentally, you couldn't remove it."

Simonetti is now experimenting with nanoparticles to create ice that more closely resembles the properties of a metal part. The idea is to freeze suspensions of nanoparticles into the water to make the ice denser, heavier and mechanically stronger.

Simonetti's taking calls from many industries, including engineering firms, car manufacturers and the military. He thinks the publication has helped establish legitimacy in his cryoultrasonic approach, as well as limit skepticism. He, too, doubted the approach at first.

"It's entirely new. Whenever you have something that is so novel, there are a lot of skeptics from the academic community," he says. "When you freeze water, it looks terrible. You think, 'This is not going to work.'"

Simonetti pulls the finished block of ice out of the freezer to inspect. The ice completely encases the metal part. As Simonetti holds up the ice, he can see right through it. It's as clear as an ice sculpture of a swan and, somehow, just as impressive.

More information: F. Simonetti et al, Experimental methods for ultrasonic testing of complex-shaped parts encased in ice, *NDT & E International* (2019). DOI: 10.1016/j.ndteint.2019.01.008

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