

NIST sharpens the 'Charpy' test for more precise impacts on industrial materials

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A decade before an iceberg shattered the hull plates of the Titanic and half a century before a plague of brittle fractures started sinking Liberty ships during World War II, scientists in the United States and France had devised a novel, and strikingly simple, method for measuring the way metal reacts to impact.

Today, that method, with some upgrades and refinements, remains the standard test used worldwide to judge the impact resistance of metals used in bridge construction, high-pressure boilers, ocean ships, armor plate, nuclear pressure vessels, and other applications. Now it is about to be significantly improved, thanks in large measure to a cooperative research program by scientists at the National Institute of Standards and Technology (NIST).

"Knowing the dynamic tensile and yield properties at very high loading rates can be critically important in evaluating the crash-worthiness of devices and structures," said Enrico Lucon, a veteran engineer and testing expert in NIST's Charpy lab in Boulder, Colorado."

Every kind of metal has some combination of brittle and ductile (softer or less brittle) properties. The measurements that reveal those properties, called Charpy tests, are made on a machine that consists of a long, weighted arm, suspended by an axle, that swings like a pendulum. A notched specimen of the material to be tested is placed on the base of the machine at the lowest point in the pendulum's arc.

The arm is raised to an exactly measured height and then released. It swings down, breaking the sample, and continues its swing upward until it reaches a maximum height that is lower than its initial height. The difference between the two heights is a measure of how much energy was expended in breaking the sample.

In its classic form, the machine has many sources of error, and it is difficult to compare results from different devices. Since the 1920s, researchers have been fitting out the pendulum's wedge-shaped impact edge (called a striker) with instruments known as strain gauges, which send electrical signals proportional to the deformation of the striker during impact.

Instrumented strikers offer the possibility of greatly enhanced accuracy. At present, however, "there is no international agreement on the shape and configuration of the striker, where the strain gauges are placed, how many gauges are used, how close to the striking edge they are located, and more," Lucon said. "We've been working for a couple of years now, and we're about halfway to the point of proposing an optimized design for instrumented Charpy strikers."

NIST researchers are also working on an important related problem: accuracy concerns about the present widely used method of calibrating the strain gauges. It is a static process (static calibration) in which an exactly known force is applied to the striker and the resulting voltage is recorded.

"But impact is a highly dynamic process," said NIST physicist Akobuije Chijioke, whose group has partnered with the Charpy lab to develop improved calibration of the instrumented strikers. "The ratio of force and output voltage from the striker can change greatly during an impact that typically lasts from less than 1 millisecond to 5 milliseconds."

Methods have been developed to improve upon this, for example by taking advantage of the absorbed energy measurement in a Charpy test, but a true dynamic calibration of the Charpy force measurements is lacking. "To address this, we are developing an SI-traceable true dynamic calibration," Chijioke said. The process employs a dynamically calibrated force transfer standard, brought from the Dynamic Force Metrology Lab in Gaithersburg, Maryland.

NIST's instruments can record millions of strain and voltage readings per second. "To determine the proportion of ductile to brittle fracture in various steel types, you need that kind of resolution," Lucon said.

The Charpy researchers are also testing redesigned strikers. "The design of the striker affects how well you can calibrate it, and how much information you can get out," Chijioke said, such as how much a given force will move, or displace, the material of interest. "The goal is to provide SI-traceable, consistent force measurements that enable comparable force-time data across all types of Charpy machines and achieve a true dynamic calibration procedure for instrumented Charpy strikers. The design of the striker impacts our ability to accomplish this." The NIST team is closing on a design that Lucon called "not final, but extremely promising."

Of course, not all the machines in industrial use have instrumented strikers. But all of them still need to be verified periodically using standards issued by organizations such as the American Society for Testing and Materials (ASTM) International. This is done by using reference steel test specimens. NIST plays a key role in this process worldwide by providing standard test specimens (usually 10 x 10 x 55 mm, about the size of a human finger) available in three levels of toughness, which can be used to verify machines with two different striker configurations.

NIST certifies its reference specimens using three of the Boulder lab's multiple Charpy machines, and ships out about 2,000 sets of five specimens per year. Because impact toughness changes with temperature, NIST requires its specimens to be tested at -40 °C. Most other national metrology institutes produce specimens that have to be tested at room temperature.

"Because of its combination of simplicity and reliability, the Charpy test has been embedded into steel specifications all over the world to ensure the toughness needed for critical infrastructure applications such as bridges, building structures, nuclear infrastructures, and pipelines," said NIST materials scientist James Fekete, who heads the division that includes the Charpy lab. "The NIST program combined with the ASTM testing standard ensures a globally reliable energy scale for the Charpy test with the lowest uncertainties obtained to date"

Provided by National Institute of Standards and Technology

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