Deformation fingerprints will help researchers identify, design better metallic materials

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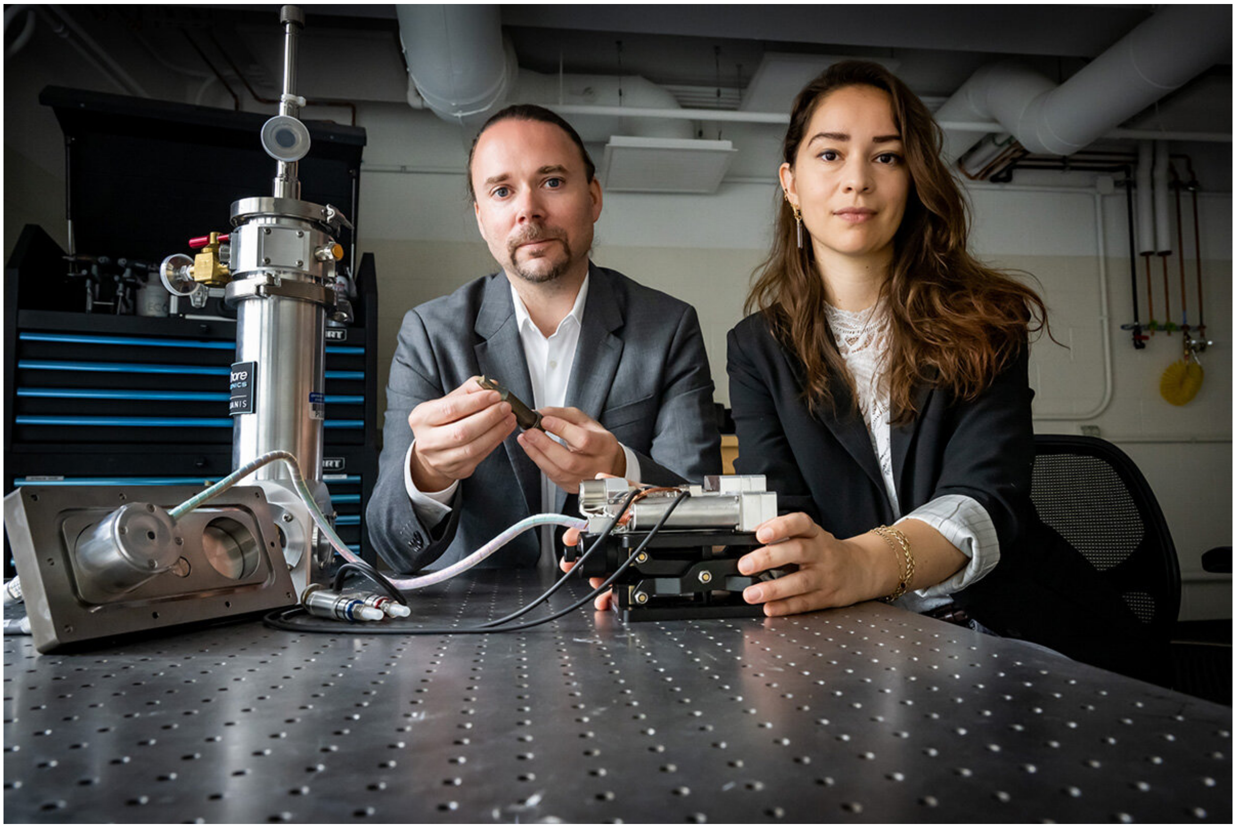
The foreground shows a fractured sample of an alloy used in aircraft engines. In the background, each color represents an orientation of the metal's crystal structure. The gray lines indicate a specific measurement and inform how the metal deforms. The color of the lines indicates how intensely the atoms have been disrupted as a result of mechanical loading. Credit: Fred Zwicky

Engineers can now capture and predict the strength of metallic materials subjected to cycling loading, or fatigue strength, in a matter of hours—not the months or years it takes using current methods.

In a new study, researchers from the University of Illinois Urbana-Champaign report that automated high-resolution electron imaging can capture the nanoscale deformation events that lead to metal failure and breakage at the origin of metal failure. The new method helps scientists to rapidly predict the fatigue strength of any alloy, and design new materials for engineering systems subject to repeated loading for medical, transportation, safety, energy and environmental applications.

The findings of the study, led by materials science and engineering professors Jean-Charles Stinville and Marie Charpagne, are published in the journal *Science*.

Fatigue of metals and alloys—such as the repeated bending of a metal paperclip that leads to its fracture—is the root cause of failure in many engineering systems, Stinville said. Defining the relationship between fatigue strength and the microstructure is challenging because metallic materials display complex structures with features ranging from the nanometer to the centimeter scale.



Materials science and engineering professors Jean-Charles Stinville and Marie Charpagne captured the rare nanoscale deformation events at the origin of metal failure that can help researchers design new materials for medical, transportation, safety, energy and environemental applications. Credit: Fred Zwicky

"This multiscale issue is a long-standing problem because we're trying to observe sparse, nanometer-sized events that control macroscopic properties and can be captured only by investigating large areas with fine resolution," Charpagne said. "The current method for determining fatigue strength in metals uses traditional mechanical testing that is costly, time-consuming and does not provide a clear picture of the root cause of failure."

In the current study, the researchers found that the statistical investigation of the nanoscale events that appear at the metal surface when deformed can inform fatigue strength of metals. The team is the first to uncover this relationship using automated high-resolution digital image correlation collected in the scanning electron micrsocope—a technique that compiles and compares a series of images recorded during deformation, Stinville said. The researchers demonstrated this relation on alloys of aluminum, cobalt, copper, iron, nickel, steel and refractory alloys used in a large variety of key engineering applications.

"What is remarkable is that the nanoscale deformation events that appear after a single deformation cycle correlate with the fatigue strength that inform the life of a metallic part under a large number of cycles," Stinville said. "Discovering this correlation is like having access to a unique deformation fingerprint that can help us rapidly predict the fatigue life of metallic parts."

"Designing metallic materials with higher fatigue strength means safer, more resilient and durable materials," Charpagne said. "This work has societal, environmental and economic impacts because it sheds light on the micro and nanoscale parameters to tune to design materials with a longer life. I think this work will define a new paradigm in alloy design."

More information: J. C. Stinville et al, On the origins of fatigue strength in crystalline metallic materials, *Science* (2022). DOI: 10.1126/science.abn0392

Provided by University of Illinois at Urbana-Champaign

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