Breaking point: Researchers discover method to determine when metals reach end of life

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We live in a world almost completely dependent upon machinery. Since the creation of the simple wheel, humans have found ways to increase quality of life and advance scientific knowledge using these devices. Though the prevalence of machinery has allowed us to build bigger, travel faster and create more quickly with complexity increasing as science advances, our dependence upon them has limitations. Everything that moves can and will break, especially metals under strain. And when they fail, the consequences can be catastrophic. LSU's Michael Khonsari has developed and proven a novel method to avoid the danger that comes with reaching the breaking point.

Under the direction of Khonsari, Dow Chemical Endowed Chair in Rotating Machinery, the Center for Rotating Machinery in LSU's College of Engineering has developed a method to determine when metals under repeated back and forth stress will reach their breaking point. This discovery has the potential to save industry millions of dollars – and also save lives.

"It has far-reaching implications ... this isn't going to impact just one industry or field," said Khonsari. "Machines impact our everyday lives, from automobiles to aviation, and breakdowns can cause immense complications. We're working to minimize those while maximizing efficient output."

The point at which materials reach a breaking point is a major concern. Chemical plants, for instance, rely on vast amounts of machinery to run efficiently and safely at all times. An emergency shutdown of just one piece of machinery could cost millions of dollars at best; at worst, it can cost lives.

"We have determined that most metals respond similarly when subjected to external cyclic stress that causes fatigue. While any kind of repetitive stress – bending, torsion, tension and compression – results in an increase in temperature, the moments before breakdown are precipitated by a sudden, drastic rise in temperature," said Khonsari. "What's more, we've determined that as a metal degrades, the amount of disorder generated within it keeps rising to a maximum value just before it fractures. And this maximum value happens to be a unique property of the metal. This discovery means we can anticipate the moment of failure and shut down before that moment arrives."

To reach these answers, Khonsari and his group had to go back to some basic questions and formulate their research in a totally new way.

"We had to ask ourselves those very fundamental questions. What is fatigue? What is wear? How to we characterize fatigue and wear? And is there a unifying principle behind all of these phenomena that basically cause degradation in a system? We had to start from the ground up."

He and his research team found that degradation results in disorder within a material and increases its entropy, a thermodynamic principle manifesting itself in an increase in temperature. They hypothesized that, at the moment of material failure, the total accumulated entropy is constant and independent of frequency, load or specimen size. The research was originally published in the Proceedings of the Royal Society of Mathematical, Physical & Engineering Sciences.

"The science base that underlies modeling and analysis of machine and structure reliability has remained substantially unchanged for decades.

And unfortunately, a significant gap exists between available technology and science to capture degradation of machinery and provide early failure prediction," said Khonsari. "Fortunately, we were able to make significant strides toward closing that gap."

Using infrared cameras and cutting-edge computer technology, they ran tests analyzing bending and torsional stress of common metals such as aluminum and stainless steel. The thorough testing proved their hypothesis – the total accumulated entropy before fracture occurred was constant. In other words, it is a metal property. This led them to their next line of questioning.

"We essentially found an end to the life of certain materials in which you can monitor entropy accumulation to avoid catastrophic failure, so why not use this information to automatically stop the machine when the system reaches, say, 90 percent of its life?" said Khonsari. "Computerized monitoring systems and the algorithms and signal relay capable of doing so were all developed here at the Center for Rotating Machinery at LSU. Naturally, there was a process of trial and error, but it's all been tested and verified now. It's the real thing."

Because of the LSU College of Engineering's stature in industry in Louisiana and around the globe, Khonsari is confident that this research won't simply sit unused in a lab. It meets current industry needs. He knows, because the college meets with industry representatives on a regular basis to determine just that.

"The LSU College of Engineering's industry connections have been a huge help to us during every stage of this process," said Khonsari. "Research and development is not a quick process. There are many factors, including safety, that have to be considered and tested. Once we have tested it at LSU and feel confident that the product is up to par, it's a great advantage to then use it on a preliminary basis in industry situations so we can see how it performs outside the laboratory environment."

Khonsari submitted invention disclosures describing the technology to the LSU Office of Intellectual Property, Commercialization and Development and two patents are pending. The office is currently investigating licensing and commercialization opportunities.

"Before our venture into this area, research relating to fatigue was slow and incremental," said Khonsari. "Now, we're looking at potentially transformative new ideas. There are possibilities for this to be applied in nearly every aspect of our lives. Imagine being able to know before an airplane element breaks, a helicopter blade cracks or the brakes in a car fail. Things like this are possible through future applications of our work. And it all happened at LSU by a team of researchers at the Center for Rotating Machinery."

Provided by Louisiana State University

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