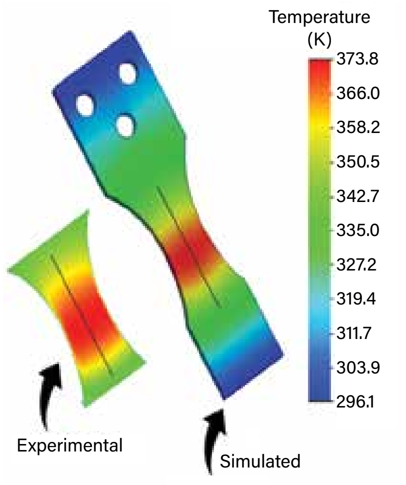
Entropy Modeling: A Breakthrough in Equipment Life Prediction

Time is the adversary of physical infrastructure in every industrial sector. Materials, components, and systems irreversibly degrade due to time, with use and environmental conditions acting as accelerants. Degradation leads to loss of performance and loss of structural integrity. To manage risk, industries expend significant resources on materials, maintenance, and remediation. According to Siemens AG, nearly $1.5 trillion was projected as lost in 2022 due to production outages across the Global Fortune 500 industrial/manufacturing companies. These economic impacts provide strong incentives for improving asset monitoring technologies and developing new materials and manufacturing methods.

In thermodynamic terms, as materials degrade, the disorder of the system accumulates, increasing entropy. The degradation problem is complex, given a material's use within an environment (*e.g.,* corrosive conditions) and the synergistic effects of these accelerants. But the underlying mechanism is the accumulation of entropy.



▲ The measured and simulated temperature distributions in a fatigue specimen are shown. The results are used in the novel entropy-based approach to forecast a component's remaining useful life within 10% of experimental tests.

A multi-scale, entropy-based degradation prediction technology with materials analysis is the cornerstone of the Center for Innovation in Structural Integrity Assurance (CISIA). CISIA, an NSF-funded Industry-University Cooperative Research Center, is led by Louisiana State Univ. and Louisiana Tech Univ. and collaborates closely with members across the industrial and manufacturing sectors.

CISIA has developed new, innovative methods for assessing and predicting the degradation of equipment and their materials of construction. Predicting the remaining useful life of materials from fundamental principles of irreversible thermodynamics (entropy) is being pioneered for condition monitoring and early failure warning. This CISIA patent-pending technology has been applied to low- and high-cycle fatigue, as well as constant- and variable-loading sequences. Importantly, the technology does not require prior loading history information. Fatigue entropy constantly accumulates in a material, independent of loading conditions. Fracture occurs when the fracture fatigue entropy threshold of the material is reached.

The methodology for condition monitoring couples entropy modeling, which accounts for the temperature environment, with thermography to predict the remaining useful life to within 10% of experimental tests. The model will be extended to a variety of materials and other degradation mechanisms (wear, corrosion, and their combination). Furthermore, novel but relatively simple sensor approaches for assessing the remaining useful life of materials are being demonstrated and integrated into a systems approach.

For areal monitoring of pipelines, wellbores, vessels, and other equipment, CISIA is demonstrating a noninvasive system to identify very small leaks of gases and liquids. Traditionally, gauges and/or sensors measure only at discrete locations and require an extensive number of instruments to monitor a large area. This novel approach uses a combination of distributed fiber optic sensors coupled with advanced signal processing and modeling. CISIA's researchers have successfully demonstrated that the approach can reliably detect, locate, and quantify very small leaks (<0.3 L/sec, to as low as 0.04 L/sec) in an experimental pipeline (4-in. diameter) even in the presence of environmental noise.

"The strength of CISIA truly lies in the systems approach, focusing not just on pioneering entropy methodologies to remaining useful life prediction, but also on structural integrity detection, mitigation, and rehabilitation technologies across the application fields," says Nersesse Nersessian of Mide Technology Corp, who chairs CISIA's Industrial Advisory Board.

The Center also applies insights from its research on aging infrastructures to design, engineer, and manufacture new advanced materials. Studying the manufacturing parameters for a revolutionary, solid-state additive manufacturing technology (MELD) yields insights into structure-mechanical property relationships, and these linkages will be used to enhance reliability across industries.

CISIA is also positioned to introduce new R&D areas and add members to further meet the challenges and needs in materials and structural integrity. According to Nersessian, "Several member companies have already begun funding separate efforts to transition the pre-competitive research into real products." CEP

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