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FATIGUE AND FRACTURE ACROSS SCALES: MACHINE LEARNING FOR INTERPRETATION, ACCELERATION, AND DISCOVERY

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ABSTRACT

Understanding and controlling fatigue-driven damage in structural materials remains one of the most challenging problems in computational mechanics, largely owing to the inherently multiscale and stochastic nature of crack initiation, propagation, or even possible self-healing. Classical continuum models, while powerful, struggle to connect the atomistic origins of unit mechanisms (grain-boundary migration, nanovoid formation, dislocation emission) to the emergent, macroscopic fatigue response observed in experiments. Bridging these scales demands not only advanced multiscale simulation strategies, but also new probabilistic frameworks for learning, interpreting, and eliciting the complex interactions that drive fatigue processes.

Machine learning and data-driven methods are increasingly offering new paths forward, not simply as replacements for physics-based models, but as powerful complements that can accelerate simulation, extract structure from high-dimensional data, uncover governing relationships that are not amenable to closed-form derivation, and make probabilistic predictions in high-dimensional spaces. This invited session brings together researchers working at the intersection of fatigue and fracture mechanics with machine learning, interpretable AI, generative methods and data-driven modeling. This session will highlight contributions spanning the full spectrum of this intersection: surrogate and reduced-order models for cycle-by-cycle fatigue evolution; neural operators and foundation models for crack propagation and damage field prediction; symbolic regression and equation-learning approaches that recover interpretable fatigue laws from simulation and/or experimental data; probabilistic and Bayesian frameworks for multiscale bridging and uncertainty quantification in fracture predictions; diffusion and flow matching models and multimodal data fusion strategies that bridge experiments and simulations into shared representations of damage mechanisms. Contributions addressing model validation, generalizability across material systems and loading conditions, and the challenge of limited or noisy experimental data are particularly encouraged.

This session aims to foster dialogue across computational mechanics, materials science, statistical physics, and machine learning communities around a shared question: how do we build predictive, interpretable, and trustworthy models of fatigue and fracture that are grounded in physics yet empowered by data?