

FATIGUE AWARE DESIGN OPTIMIZATION

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Abstract

Fatigue performance is often evaluated after a structural design has been finalized, typically using cycle counting techniques such as rain flow counting combined with cumulative damage laws. While effective for post design verification, these methods require explicit cycle identification and are difficult to integrate consistently into gradient based structural optimization, particularly for complex geometries and multi axial loading.

In this work, fatigue modeling is embedded directly within a structural optimization framework using the Ottosen, Stenström and Ristinmaa (OSR) continuum high cycle fatigue model. By formulating fatigue evolution in stress space based on a moving endurance surface and an internal scalar damage variable, the approach eliminates the need for explicit load cycle extraction. The position of the endurance surface is governed by a back stress internal variable that evolves based on the stress history. Fatigue damage develops whenever the stress state lies outside the endurance surface and moves away from it.

Fatigue evaluation is performed using stress histories obtained from a small number of linear finite element analyses corresponding to characteristic load cases. Variable amplitude loading is represented through linear superposition of these cases, enabling efficient fatigue assessment without resolving the full temporal load sequence.

The fatigue model is integrated into an optimization framework supporting shape optimization, topology optimization, and simultaneous shape and topology optimization. A fully consistent adjoint sensitivity analysis is implemented and verified, ensuring accurate gradients of fatigue related objectives and constraints. This enables systematic design updates that directly minimize fatigue damage or enforce fatigue performance requirements.

The optimization results reveal a strong correlation between stress concentrations and damage evolution. Targeted geometric modifications reduce these concentrations, resulting in lower damage rates and improved fatigue performance. The framework thus promotes structural layouts that are not only stiff but also fatigue resilient.

The study demonstrates that continuum based fatigue modeling can be effectively incorporated into gradient based structural optimization. By avoiding explicit cycle

counting and instead relying on a damage evolution law, the proposed approach provides a computationally efficient method for fatigue driven design, enabling fatigue considerations to transition from a post design verification step to guiding early stage structural development.