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ACCELERATED MULTIPLE TEMPORAL SCALE COMPUTATION FOR FATIGUE LOADINGS IN COMPOSITE MATERIALS

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Modeling failure that occurs during fatigue loadings presents a challenge for heterogeneous and composite materials. Many heterogeneous material systems, such as carbon fiber reinforced polymer composites, exhibit good durability but can and do fail under fatigue loadings. Inadequate fatigue modeling for these materials leads to overly conservative design strategies to prevent sudden and catastrophic failures foretold with few visible indications. Highly conservative design strategies limit the potential of the composite to provide high performance. Accurate and efficient modeling of composite failure due to fatigue loading provides great potential for design and maintenance of composite components in high performance applications.

Continuum damage mechanics (CDM) has been popular in modeling the failure of composite materials in recent years. However, the computational intractability associated with solving a nonlinear fatigue failure problem is substantial due to the large number of time steps required to model a structure's entire life. This intractability has been addressed using a number of fast time integration methods including cycle jump methods [1], manifold-based multitemporal methods [2], wavelet transformation based approaches [3], and computational homogenization based multiple temporal scale methods [4]. Computational homogenization offers a powerful multiscale modeling approach. In fatigue loadings, a disparity exists between the characteristic loading period and the overall life of the structure leading to the presence of multiple temporal scales. Computational temporal homogenization eliminates the need to resolve every loading cycle in the life of a composite structure addressing the computational intractability associated with modeling fatigue. Recently, Oskay and coworkers [5] developed a novel temporal homogenization approach using a fixed point homogenization operator. While temporal homogenization methods have been applied successfully for life prediction, it still remains computationally costly to perform large size structural analysis, a class of problems to which fatigue modeling offers the greatest potential benefit.

In this work, a new accelerated multiple temporal scale homogenization based model is proposed. The proposed approach relies on stepwise-linear approximation of microchronological (single-cycle) problems using the assumption that damage accumulation within a single cycle remains small. The accelerated multiple temporal scale algorithm provides a high degree of computational efficiency without a significant loss of accuracy. This is critical to the prediction of life and failure in large-scale structures.

We performed numerical comparisons between the accelerated multiple temporal scale homogenization method and direct cycle-by-cycle simulations for both a fatigue sensitive, scalar continuum damage mechanics model for quasi-brittle materials and a reduced order multiscale damage model for carbon fiber reinforced polymer composites. For both constitutive models, a high degree of accuracy is maintained while obtaining a significant gain in computational performance.

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