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A new vision to fatigue fracture modelling of composite materials via employing the phase field numerical technique

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Abstract

The phase field method is shown to be effective in modeling fatigue fractures in composite materials in this commentary. By simulating crack initiation and propagation naturally, it captures complex microstructural interactions. It enhances fatigue life predictions by integrating statistical models, making it valuable for optimizing advanced composite materials.

In recent years, fatigue fracture in composite materials has gained a great deal of attention, particularly with the advent of advanced numerical techniques such as the phase field method. It is particularly capable of simulating the complex behavior of fatigue fractures, making it a promising avenue for both researchers and engineers. A phase field method provides an accurate model of fatigue behavior of composite materials subject to cyclic loading by incorporating crack initiation and propagation naturally without the need for additional fracture criteria. As a result of the phase field method, cracks are represented as continuous variables rather than discrete entities due to the concept of a diffuse interface. The interaction between different phases in composite materials can cause intricate fracture behavior because of this characteristic. Several studies have demonstrated the effectiveness of phase field models in capturing the multifaceted nature of fatigue fractures in composites, emphasizing their potential to provide insights into damage mechanisms that are often overlooked in traditional models [1, 2].

A key advantage of the phase field method is its capability to simulate the entire fracture process, from initiation to propagation, without requiring predefined crack paths. Composite materials are particularly vulnerable to crack growth patterns caused by their complex microstructure. The phase field method has been proven to be effective at predicting fatigue crack growth in fiber-reinforced composites, which takes fiber orientation and matrix properties into account [3, 4]. Using a two-dimensional boundary value problem, researchers illustrate anisotropic fracture evolution in composite materials. Fig. 1 shows the geometry and boundary conditions for fracture evolution by the present model; by blanking the phase-field values of $d \geq 0.95$, we can see crack propagation in vivid detail [3]. Simulation of these interactions can provide a better understanding of how composite materials respond to cyclic loading conditions [5].

In addition, fatigue failure in composite materials follows a statistical pattern, which is well aligned with the phase field method. To analyze fatigue, the inherent variability of material properties and loading conditions is taken into account [6]. For better prediction of fatigue life, statistical modeling has been integrated with phase field simulations, such as the Weibull distribution [7]. By integrating the microstructural features of composites with fatigue behavior, a better understanding of fatigue behavior can be gained, allowing for more reliable design and optimization strategies.

Experiments have shown that phase field methods can be used for fatigue fracture modeling. The use of phase field approaches to model failure limits and crack growth rates has been demonstrated under diverse loading conditions in the research on aluminum-carbon fiber reinforced composites[8]. Our findings demonstrate that the method works and can predict real-life composite material performance.

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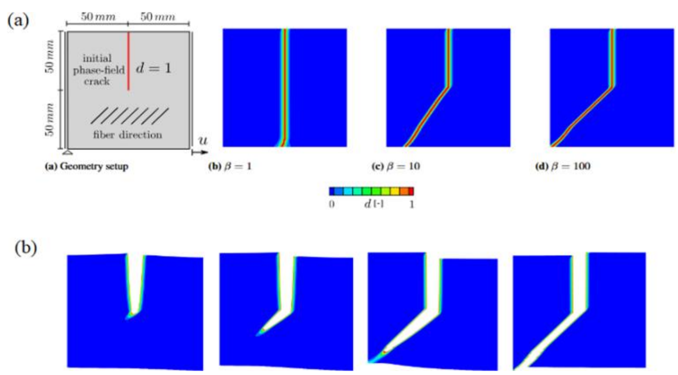

Fig. 1 (a) Fracture patterns at various ratios β (b) Fracture evolution at ratio blanking the phase-field [3].

It has also been applied to advanced composites, such as those reinforced with nanoparticles, along with its application in traditional composite materials. Researchers have indicated that nanoparticles can significantly enhance the mechanical properties of composite materials, but they also add complexity to fatigue behavior. Due to the way the phase field method models these complexities, the method is an invaluable resource for researchers who are trying to optimize the performance of next-generation composite materials [9].

Using a phase field approach, it is also possible to accommodate mixed-mode loading conditions that are common in practical applications, including mixed-mode loading scenarios. The phase field method provides insight into fracture behavior under mixed mode I/II loading by simulating fatigue crack growth under mixed mode I/II loading. For composite structures subjected to complex loading environments, this adaptability is essential for building robust predictive models.

As a result, the phase field method provides a significant contribution to fatigue fracture modeling in composite materials. The method's ability to capture the intricate interaction between microstructural features and loading conditions, coupled with its statistical approach to fatigue analysis, makes it one of the leading methods in this field[10]. Research will continue to develop phase field methods in order to develop more resilient and efficient materials for a wide variety of applications, combining experimental data with statistical models and integrating phase field methods with experimental data as research continues.

Data availability

No data was used for the research described in the paper.

Declaration of competing interest

The authors declare that there are no competing interests.

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Authors' contribution

Saeid Sahmani: Conceptualization and Writing – Original Draft Preparation and Visualization. Investigation, Supervision, and Writing – Review & Editing.

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