A PHASE FIELD FATIGUE MODEL FOR COMPLEX LOADING SITUATIONS

Sikang Yan[1]*, Ralf Müller[2], and Bahram Ravani[3]

[1]University of Kaiserslautern, Germany, [2]Technical University of Darmstadt, Germany
[3]University of California Davis, CA, USA
** Presenting Author email: yan@rhrk.uni-kl.de*

Abstract

The phase field method for fracture mechanics has drawn a lot of attention in the past decade because of its simple formulation and easy implementation. Recently, the phase field model is also applied for fatigue fracture for a uniform loading. However, there is still a lack of studies on how to consider complex loading cases in the phase field fatigue model. In this work, we extend the phase field model for non-uniform loading situations by combing it with the rainflow counting algorithm.

1. Introduction

The core idea of the phase field method is to use a continuous variable s to represent discrete continuous phenomena. The advantage of the phase field model is its monolithic framework. All the fatigue crack evolution scenarios are governed by one single equation – the total energy of the body[1][2]

$$\mathcal{E} = \int [(g(s) + \eta)\psi^e + \psi^s + h(s)\psi^{\mathrm{ad}}]\mathrm{d}V,$$

where ψ^e is the elastic energy, $g(s)$ is the degradation function and ψ^s is the fracture energy. An additional term ψ^{ad} is introduced associated with the accumulative fatigue driving force, and $h(s)$ models the loss of the stiffness of the material due to cyclic fatigue. It is postulated that the displacement field $\mathbf{u}$ and crack field s minimize the total energy, giving the equations to describe the crack evolution. The phase field model can recapture the most important fatigue features and reproduce the crack pattern[2].

2. Irregular loading situations and the rainflow counting algorithm

In the proposed phase field fatigue model, the individual single loading cycle is not taken for the simulation; instead, the cycle is transferred into continuous "time" as shown in Fig. 1**a**. The real discrete cyclic loading is approximated by its envelope loading, denoted by the red line. But what if the given loading is irregular as shown in Fig. 1**b**. and how could this irregular loading be transferred into the continuous "time" for the phase field simulation? The *rainflow counting* algorithm[3] is the most popular method to convert a sequence of varying loads into an equivalent set of constant amplitude loads. For the given example as in Fig. 1**b**, the first step in the rainflow counting algorithm is to reduce the time history of loading to a sequence of peaks (tensile load) and valleys (compressive load). Here the peaks are the points B, D, F, and H; and the valleys are the points A, C, E, G, and I, where the point I is the same point as A since this block of loading is assumed to be repeated. Next, the entire block of loading schemata is turned clockwise for 90 degrees and rearranged from the highest peak, in this case from point D as shown in Fig. 1**c**. As the name "rainflow" indicates, the next step is to image raindrops starting from each peak and let them flow down to the valleys. The "flow of rain" will stop in the following cases:

a. It reaches the end of the loading time history, e.g. the flow from the peak D.
b. It encounters a flow of early stage, e.g. the flow from the peak F, which meets the flow from the peak D.
c. If an opposite tensile peak has greater or equal magnitude than where it starts.

Following this rule, the demonstrated example has four "flows of rain" (D to G, F to E, H to C, B to I(A)), which correspond to the range of the applied stresses (see Fig. 1**c**.). Thus, this entire irregular loading scenario is reduced to a set of simple stress reversals as shown in Fig. 1**d**., of which the enveloping loading (denoted by the red line) is used as an approximation of cyclic loading for the phase field simulation. Fig. 1**e**. and 1**f**. demonstrate the simulation results of the applied loading generated by rainflow counting algorithm and the crack length. The result shows that the first three blocks of cyclic loading are mostly involved in the crack nucleation process and the last block is mainly contributed to the crack propagation, which begins after 1549410 cycles.

The rainflow counting algorithm is related to the hysteresis curve and the plasticity of the material, and it is to be noticed that the loading sequence effect is ignored by the rainflow counting algorithm. Different loading sequences might influence the fatigue life from the simulation results.

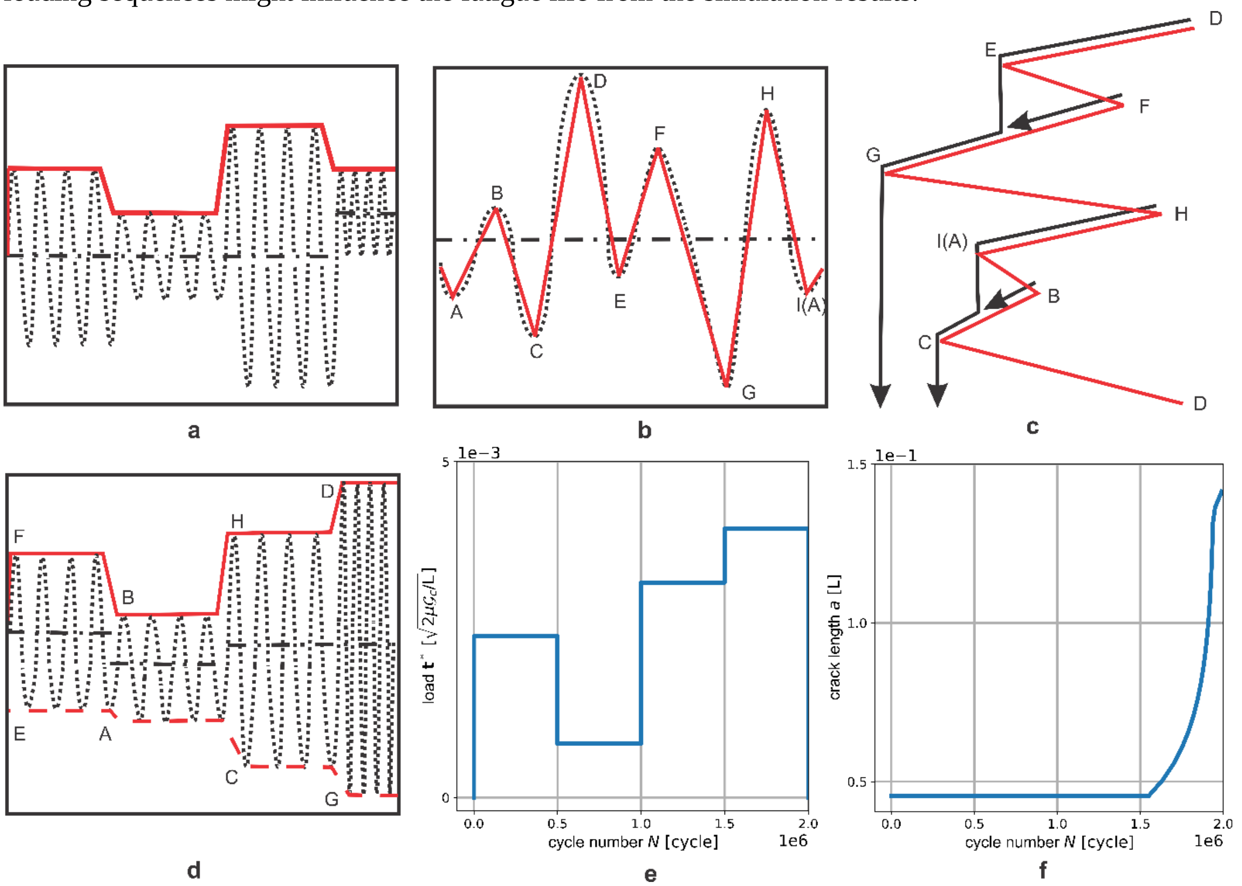

Fig.1 – A simple illustration of rainflow counting algorithm and its application in the phase field model.

3. Conclusions

In this work, a phase field fatigue model is extended to account for irregular loadings by applying the rainflow counting algorithm. Thus classical counting techniques in experimental fatigue studies are combined with fatigue simulation methods. The results show that the phase field method can predict the fatigue life and crack pattern for complex loading situations.

References

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