Fatigue crack propagation with a phase-field approach coupled to adaptive mesh refinement and cycle jump schemes

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In recent years, the phase field approach applied to crack propagation problems has gained in popularity in the scientific community. So much so that even if it was originally applied to brittle fracture (e.g. Ref. [1]), it was since extended to several other crack propagation mechanisms such as fatigue in Ref. [2]. This popularity can be explained by the flexibility of the phase field model in a finite element framework in the context of crack propagation. Indeed, it has been shown to recover complex crack patterns without adding additional propagation criterions. However, these models usually suffer from prohibitive computing time. Such efficiency issues makes it difficult to study application of industrial cases, or to perform numerical-experimental comparisons. Consequently, in this work we put forward the coupling of multiple tools to accelerate computing time of phase field fatigue crack propagation simulations. First, an adaptive mesh refinement procedure (AMR) is implemented to optimize the number of degree of freedom processed at each time step. Then an iterative cycle jump scheme inspired by Ref. [3] is coupled to adaptive mesh refinement to optimize the number of computed cycle.

It is indeed well known that using a phase field model in a finite element framework suffers from multiple efficiency drawbacks. Firstly, the regularisation of the crack discontinuity on a small length scale means that in order to capture the gradients of the physical quantities in the damage zone, a very fine mesh must be used. Since for most crack propagation simulations, crack path is not known a priori, the whole structure must be meshed very finely, yielding very high computing time. Conversely, by coupling AMR and phase field, we can use a refined mesh only where it is necessary, yielding faster computation while keeping precision. In this work a refinement criterion based on the value of the phase field is used to achieve a flexible coupling between phase field and AMR.

Secondly, the computation of a single cycle can lead to a high computing cost because of the high nonlinearity of the damaged structure behaviour. Moreover, in the case of high cycle fatigue lifetime prediction, lifetime typically consists of $N > 10^5$ cycles. In this context, we use an implicit cycle jump scheme coupled to the previously introduced fatigue phase field AMR. This iterative approach enables us to skip large number of cycles while keeping a predefined precision.

To demonstrate the capabilities of the model, multiple benchmarks of the phase field fracture literature are first studied. We validate that the introduced AMR and cycle jump schemes yield precise and efficient results and couple them both to achieve maximum efficiency gains. First, several cases of mode I crack propagation are studied to validate the coupling. Then we demonstrate the ability of the model to recover more complex crack propagation patterns such as crack kinking, branching, nucleation and coalescence.

References

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