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Damage tolerance assessment directly from CAD: (extended) isogeometric boundary element methods (XIGABEM)

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Abstract

We develop in this work a procedure for obtaining the fatigue life of complex structures directly from Computer-Aided Design (CAD) data, without any mesh generation or regeneration as the cracks evolve. The method relies on a standard isogeometric boundary element method (BEM) where the same basis functions are used to both describe the geometry of the component and approximate the displacement and traction fields.

To capture the stress singularity around the crack tip in the framework of linear elastic fracture mechanics, two methods are proposed: (1) a graded knot insertion near crack tip; (2) partition of unity enrichment.

A well-established CAD algorithm [1] is adopted to generate a smooth crack surface as the crack grows. The M integral and J_k integral methods for the extraction of stress intensity factors are compared in terms of accuracy and efficiency. The numerical results are compared against closed-form solutions as well as other numerical methods, namely the collocation BEM with a Lagrangian basis, a symmetric Galerkin BEM and extended finite element methods. The crack growth paths and fatigue lives obtained by the proposed method are validated using experimental data.

Key words: Isogeometric analysis, partition of unity enrichment, linear elastic fracture, boundary element method, fatigue crack growth

The isogeometric analysis (IGA) based on finite element methods was proposed by [2]. The idea of IGA is to use the same shape functions to describe the known CAD geometry and the unknown field variables. However, CAD systems typically only provide the boundary of the domain [1] and do not provide any description of its interior. Hence, in its original form, as proposed in [2], IGA still requires an additional parametrization of the domain's interior, which has been the subject of much effort since the first inception of the method.

To resolve this issue, the isogeometric collocation BEM was developed and exercised in elastostatics by Simpson et al [3] to perform stress analysis directly from CAD and without any meshing [4]. Implementation aspects of the method were provided in [5] and the method was extended to three-dimensional stress analysis of complex structures in [6].

In this work, we advance the concept we proposed in [3] to predict the fatigue life of engineering structures using a simple Paris law. In conventional fatigue simulations as performed industrially [7] using the finite element based methods, the key difficulty is the accurate computation of the crack driving force, namely the stress intensity factors (SIFs). The second difficulty is that the domain mesh used for stress analysis and hence for the detection of "sensitive" regions in the component, where initial flaws are introduced, is typically at least one order of magnitude too coarse to provide quality SIFs. The third difficulty lies in the geometrical complexity of the domain which, if the predicted fatigue life is deemed inadequate must be redesigned. For each new design, and for each crack configuration, a new mesh typically needs to be generated, not only to conform to the new chosen geometry, but also to properly resolve stresses in the vicinity of the crack tip. Even when enriched finite element methods are used, some level of remeshing is required [7].

Collocation BEM is an strong contender to attack fracture mechanics problems, because it requires only boundary discretization, simplifies the insertion of new crack segments during growth and offers superior accuracy for the computation of the SIFs for the same number of degrees of freedom compared to other methods. Since BEM requires only boundary discretization, it is also an ideal partner for IGA. We show that isogeometric dual BEM with or without partition of unity enrichment is a robust and accurate method to deal with for fracture simulations and that such simulations require no meshing nor remeshing in the conventional sense.

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