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MULTI-SCALE STRUCTURAL MECHANICS FOR ADVANCED AIRCRAFT DESIGN

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Abstract. Finite elements (FE) is the analytical workhorse for structural and solid mechanics. As applied to systems with evolving topologies, such as crack initiation and propagation, or fracture in anisotropic media, such as laminated composites, FE has limitations. We present a new method for analysis of laminated composites that address these limitations.
Keywords. Meshfree, crack morphology, physics-based modeling, laminated composites

1 INTRODUCTION

Physical phenomena in some important areas, such as fracture, fundamentally occur in a discontinuous fashion. On the other hand, most methods for solving structural mechanics problems, e.g. the finite element method, are formulated to solve for continuous field variables. To model a crack in a continuum model requires embedding some model of discontinuity into the continuous formulation. Numerous approaches using this methodology have been introduced, such as X-FEM, cohesive cracks, element erosion, etc. These methods have achieved some degree of success. Purely discrete models, such as molecular dynamics (MD), can naturally evolve to open up discontinuities in a material. However, the number of molecules required for MD simulations capable of modeling practical engineering fracture problems is prohibitively large. Thus, there seems to be a place for a simple method to solve the continuum equations, but easily incorporate discontinuities. For laminated composites, the fiber orientation has a profound effect on how cracks can propagate. In mesh-based analysis methods based, the mesh orientation may influence the crack direction, but it may conflict with the physical requirements dictated by the fiber orientation. This paper presents such a method based on one of the so-called meshfree methods, in this case the Reproducing Kernel Particle Method (RKPM). The method explicitly models cracks and changing topology and is formulated to reduce or eliminate discretization choices from influencing the solution. Further, the model naturally provides a mechanism for incorporating information that is not contained in the governing continuum equations to determine crack initiation and direction. In some sense, this latter property may be viewed a sort of multi-scale model.

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2 RKPM AND CRACK MODELING

The Reproducing Kernel Particle Method was first introduced in [1] and provides a method to construct a function basis for use in Galerkin solutions to partial differential equations without using a mesh, but rather through locally and perhaps dynamically determined interactions between nodes. Since a mesh is not required to form the function space, it can evolve dynamically, and in particular, can be adjusted as the material topology changes. The RKPM method constructs a local interpolation field centered at each node that is based on local interaction with neighboring nodes. By introducing a visibility condition during a calculation, one can selectively limit the interaction between nodes to effectively cut the material.

A crack morphology and propagation algorithm that conserves mass and energy was developed for two-dimensions in [2]. This paper presents the extension of this algorithm to three-dimensional through-cracks of directed surfaces. The node splitting algorithm uses information determined from the constitutive model to determine when a node should be split. Based upon this damage measure the crack propagation algorithm automatically chooses crack direction and propagation. The ability to couple node splitting to a damage measure is immensely powerful. In fact, it can be viewed as a link between the structural mechanics equations and an externally (to the mechanics equations) determined quantity. There is no need for the external quantity to be continuous and its insertion into the simulation is done for each node, and is thus discontinuous. Proper selection of the external damage measure allows a researcher to incorporate information from knowledge bases, or detailed physics-based multi-scale calculations. An example of the three-dimensional algorithm applied to a pressurized cylinder with localized heating is shown in Fig. 1. The black dots represent nodes, the color contours are of the external damage.

3 Hierarchical Multiscale Modeling

The standard method of modeling composites is the continuum approach where the effect of the composite fibers are idealized as material properties of a linear elastic model. This, in a sense, is a form of the multiscale problem. The fibers themselves are too small to be modeled explicitly and so this information is included in the model in the form of material