Modeling of Damage Phenomena Using Higher-Order Finite Element Formulation

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INTRODUCTION

It is well-known that damage phenomena cannot be objectively modeled by using the classical continuum theory because the differential equations which describe the deformation process may lose the elliptic characteristic once the damage is initiated. Mathematical description of the model in that case becomes ill-posed and numerical solutions do not converge to a physically meaningful solution. To overcome these problems, most of the regularization techniques developed are based on the improvement of the classical continuum model by its enrichment with the internal length scale parameters in various forms. Among these techniques especially nonlocal theories are known, which have been shown to be the most versatile. One of them is the strain gradient continuum theory, which introduces the nonlocality in the model through additional gradient term in the strain energy density function.

METHODS

In this contribution, the two dimensional C^1 continuity triangular finite element based on the aforementioned strain gradient theory is extended to the modeling of damage and strain localization phenomena. The linear elastic material behavior is considered, where the linear and exponential damage evolution laws of quasi-brittle damage are employed. Stiffness degradation in the softening stage is governed by the isotropic damage law, where the damage variable in a point of the material depends on the highest value of equivalent elastic strain ever reached in the deformation history. Constitutive matrices are obtained prior to the softening analysis using the second-order homogenization procedure applied on the appropriate representative volume element (RVE). The deformation responses of both homogeneous and heterogeneous materials are investigated. The latter is done by varying the sizes of the adequate RVEs, considering only the academic examples of heterogeneous materials.

PRELIMINARY RESULTS

The verification of the presented damage model is made on a benchmark example consisting of a rectangular plate with an imperfect zone under tension. The results obtained are compared with the solutions from the literature, where the same numerical example is analyzed employing the EFG meshless method and assuming only homogeneous materials. Here, the study of damage behavior of heterogeneous materials is made as well. Besides, an analysis of the shear band formation along an imperfect plate subjected to compressive load is performed, and the solutions are compared with the experimentally obtained data.

DISSCUSSION

It is demonstrated that strain localization and softening phenomena can successfully and efficiently be captured by means of the proposed computational strategy. In addition, sufficiently accurate model for the softening analysis of heterogeneous materials on the macrostructural level is obtained in a rather simple way. The further research will be concerned with the damage consideration on the microlevel, where a multi-scale computational strategy will be employed.

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KEYWORDS

Damage modeling, C1 continuity finite element, Strain gradient theory, Heterogeneous material