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Article / Book Information

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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In the thesis, novel physics-based computational modeling techniques derived from the energy limiter concept for failure predictions in various important engineering materials like brittle, quasi-brittle, ductile, rock-like, rubber-like, and anisotropic composite materials are developed. Based on the idea that no existing materials could sustain a large enough strain without getting damaged, the traditional strain energy density (SED) function is modified consistently to the energy limiter theory to satisfy the condition, i.e., if the strain increases to a finite value, the SED approaches a constant which is equal to the energy limiter of the material. The energy limiter here physically presents the total energy in which the material could be sustained until it is fully broken. From the idea, the mass-field, local, and nonlocal damage models have been formulated for failure modeling in the solids. More precisely, the energy limiter-based SED functions for fracture analyses in different materials are proposed for the derivation of material constitutive and local damage laws. Then, energy decomposition techniques are further integrated into the derived damage formulations for the distinction of fracture behavior in tension and compression. For the local damage formulations, the crack band theory is also employed to treat mesh-sensitive results. The resulting governing coupled equations of motion-local mass balance equations for mass-field, a single motion equation for local damage approaches, and a system of equations of motion-nonlocal damage evolution equations for gradient-enhanced damage models have been demonstrated to be effective and promising for fracture predictions in many engineering materials like brittle (glass, ceramic, dynamic brittle failure), quasi-brittle (concrete, limestone), ductile (steel, aluminum, alloy), composite (fiber-reinforced composite), rock-like, and rubber-like media. For the numerical solutions, the proposed numerical techniques are implemented within the standard finite element method (FEM) with the aid of staggered algorithms by in-house-built computer codes with advanced programming schemes of parallel calculation and vectorization for fast and effective computational tools. The fracture analyses are also performed under different loading conditions of quasi-static and dynamic cases in which the materials are modeled from small strains to finite deformations considering isotropic and anisotropic failure mechanisms. It has been shown that the developments maintain their generality with damage in one- (1D), two- (2D), and three-dimensional (3D) solids that could be modeled under the same framework. Several advantages of the proposed damage models could be briefly summarized as (i) the mass-field/local/nonlocal damage variables are defined as the primary unknowns which are directly obtained by solving the governing/diffusion equations,(ii) no-mismatch in the interpolations of primary variables is found, i.e., the same interpolation functions can be used to approximate both the displacement and mass-field/nonlocal damage fields, which is more effective in terms of FEM analysis than traditional gradient-enhanced damage models, (iii) the material constitutive and local damage laws are naturally and newly derived based on the introduced energy limiter theory, tightening to their physical meanings, (iv) a physics-based characteristic length scale is derived, then one can understand clear physical meanings of the length scale parameter which is still questionable in most existing nonlocal/gradient-enhanced damage models, (v) in terms of FEM analysis, mesh-independent solutions for both crack paths and structural force-displacement responses are obtained, (vi) complex crack path, multiple crack growth, and failure in 3D can easily be obtained without using any additional ad-hoc criteria for the growth of crack. As compared to well-known discrete damage models i.e., the extended finite element method (XFEM), the developed model provides the smeared damage field representing the localized failure zone, which does not require tracking algorithms for the discontinuities of the displacements due to crack formation. Therefore, arbitrary cracks, complex, and multiple crack-growth problems could be simulated more effortlessly and effectively. In terms of parameters used in the fracture analysis, it will be shown for the first time in the literature a consistent procedure to determine all the parameters related to the modeled structure based on reference experiments and the energy limiter idea. Especially, the estimation of the length scale parameter which exists in the gradient-enhanced damage theory. It is important to state here that, in previous studies, the physical meanings and interpretations of the length scale are still not clear and ambiguous, it is just a selected model parameter. However, numerical results are greatly affected by the parameter, which normally leads to the so-called fitting length scale value to achieve a good numerical solution with experimental references. However, the fitting is meaningless in problems where no information is known in advance (the blind tests). From the limitations of the existing methods in interpreting the length scale parameters, in the study, the length scale parameter is understood as a problem-related value, not a model parameter that can be determined from experiments. Precisely, it is estimated from the fracture energy of the simulated system and the total energy limiter of the material which is physically drawn from the developed energy limiter concept.