論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Smoothing Gradient Damage Modeling in Brittle/Quasi-brittle Fracture: Algorithms and Applications
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出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12435号, 授与年月日:2023年3月26日, 学位の種別:課程博士, 審査員:廣瀬 壮一,佐々木 栄一,竹村 次朗,WIJEYEWICKREMA ANIL,千々和 伸浩
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12435号, Conferred date:2023/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	Civil engineering 系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Engineeging)
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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

The thesis, entitled "Smoothing Gradient Damage Modeling in Brittle/Quasi-brittle Fracture: Algorithms and Applications", consists of nine chapters, written in English. Analysis of fracture behavior of brittle and quasi-brittle materials such as concrete, ceramics, and rock is important for the design and maintenance of civil engineering structures. Among the many fracture analysis methods, the smoothed gradient damage method (SGDM) has attracted much attention as an element-independent analysis method that can appropriately represent damage bandwidths by incorporating anisotropy and nonlocality of strain. In this study, SGDM is further improved and extended to analyze various failure problems.

In Chapter 1, the background, objectives and outline of the thesis are described. The basic concept of SGDM is shown in Chapter 2. In essence, the involved contributions are divided into six parts of Chapters 3-8. In Chapter 9, the conclusions and recommendations are summarized.

In Chapter 3, a gradient-enhanced damage model with appropriate equivalent strain definitions is developed to solve the mixed-mode failure problem in concrete. In detail, three damage models with different equivalent strains are presented, and their computed results are thus compared together. The target is to find the most suitable approach for mixed-mode fracture problems in quasi-brittle materials. Chapter 4 is devoted to the numerical analysis of the damage problem under dynamic loading conditions. It is well-known that the increase of tensile strength and retardation of crack propagation can be observed in low loading rates. For high loading rates, when the critical crack speed is exceeded, the failure tends to turn from mode-I to mixed mode, and thus an interesting phenomenon called crack branching occurs. Two new rate-dependent laws are introduced to capture dynamic phenomena at low and high loading rates. Chapter 5 presents a novel gradient damage model (ASGDM) which takes account of directional damage evolution by introducing a new damage evolution equation towards anisotropic fracture in brittle materials, i.e., uniaxial fiber-reinforced composites and polycrystalline materials. The evolving gradient interaction parameter defined in the evolution equation of the smoothing gradient-enhanced damage model is redefined by integrating a second-order structural tensor, which dictates the crack propagation in the predefined crack orientation, to SGDM. Moreover, a staggered solution scheme is applied to reduce computational costs and simplify the general algorithm. In Chapter 6, to successfully model the crack propagation inside grain boundaries (i.e., intergranular fracture), the recently developed anisotropic damage model named ASGDM is augmented with additional relations, i.e., distribution tensile strength and misorientation functions. With these improvements, the material tensile strength at the boundary and within the grain can be distinguished. Thus, the developed damage model ISGDM can smoothly simulate intergranular fracture without expensive meshes at interface regions. Chapter 7 analyzes the damage process in rock-like materials with pre-existing cracks, which is not easy to simulate due to the complexity of deformation states and mixed-mode failure. A novel equivalent strain mapping formulation, a combination of a robust decomposition and three invariants of the strain tensor, is proposed to enhance the capability of SGDM in capturing fracture problems in rock-like materials. In Chapter 8, the SGDM is extended to thermo-mechanical fracture problems and becomes a new damage model called TSGDM. In particular, the heat conduction equation is coupled with governing equations of SGDM to account for the effect of temperature change on crack initiation and propagation. Also, the damage variable, an indicator of deterioration level in solid materials, is embedded in local heat flux and heat capacity to interpret the adiabatic characteristic of damage zones.

Generally, the six developed damage models presented in this thesis can capture several brittle and quasi-brittle fracture problems in isotropic and anisotropic materials. However, limitations still exist in these damage models, and thus further improvements can be made to extend SGDM to more complex fracture problems.