# Preface

This book focuses attention on the pattern formation and the evolution of crack propagation in engineering materials and structures, where efforts are made to bridge mathematical analyses of cracks based on singular integral equations to computational simulation of engineering design. The aim of this book is not only for structural engineers to understand the basic backgrounds of analyses, but also for those majoring in mathematics to see how such mathematical solutions are evaluated in industrial applications. Brittle crack propagation and fatigue crack growth are considered as the mechanisms of crack propagation, and they are investigated based on the Griffith–Irwin theory for the former, while the latter is examined by the repeated tension–compression yielding behavior including the contact mechanism of plastic wake left behind a crack tip. This monograph consists of four parts: elasticity, fracture, morphology, and design. The first two parts provide the basis of the analysis for the discussions on the fracture morphology and its numerical simulation which may lead to a simulation-based fracture control in engineering structures.

In Part I, the basic elasticity theory is summarized for two-dimensional elastic solids. The displacement vector and strain tensor, the stress tensor and Airy's stress function, and the relation between stress and strain tensors are first introduced for a homogeneous isotropic elastic body. Then, the elastic boundary-value problem is defined, and some fundamental solutions are given in Chapter 1. Stress concentration problems are investigated in Chapter 2, where the stress concentration due to an external force and to structural discontinuities such as circular and elliptic holes are solved by using Airy's stress function and the complex potentials. In Chapter 3, crack problems are solved by the complex potential method, and the elastic stress singularities near a crack tip are identified. Also, the analytical structure of the stress field is examined by a method of eigen-function expansion near a crack tip.

In Part II, analyses are made for brittle fracture and fatigue crack propagation. In Chapter 4, brittle fracture is analyzed based on the Griffith–Irwin theory, where the effects of plastic deformation are examined by considering the strip yielding model, J-integral, and stability of slow crack growth. Fatigue crack growth is discussed in

Chapter 5, in which Paris' law is introduced. Then, the effective stress intensity range proposed by Elber based on the crack closure concept and the repeated tensile plasticity range proposed by Toyosada are discussed. The effects of stress ratio and load sequence are analyzed based on a recently developed crack growth model. Fatigue and fracture are essential for the structural integrity of engineering structures, so that the results in this part are relevant to the design codes for the prevention of unstable fracture following fatigue crack growth.

In Part III we investigate morphology, i.e., the formation of single and multiple crack paths in brittle fracture and fatigue. In Chapter 6, morphological aspects of crack propagation are discussed focusing attention on the pattern formation of a system of quasi-statically growing straight cracks, which exhibits stable bifurcation phenomena, i.e., every other growing crack is arrested at a certain crack length, resulting in a self-similar pattern formation of multiple cracks. Then, in Chapter 7, we discuss a kinked and curved crack by applying the first-order perturbation method, in which crack path prediction in brittle solids is analyzed based on a crack path criterion that includes some aspects of crack path stability. The first-order perturbation is then applied to a system of kinked and curved cracks for the simulation of curved or wavy crack propagation in brittle solids. In Chapter 8, the perturbation method is extended to the second order in examining the behavior of brittle fracture along butt-weld, where the residual stress and the degradation of fracture toughness due to welding may play essential roles coupled with curved crack paths. In Chapter 9, fatigue crack paths are investigated with regard to crack path criteria, the effects of biaxial stress, and welding.

In Part IV, we consider simulation-based fracture control design. It is well known that the simulation of the formation of brittle or fatigue cracks is essential for the precise evaluation of fracture modes and fracture processes, so that several numerical simulation systems have been developed based on the finite element method, meshless method, and/or boundary element method. In Chapter 10, a numerical simulation system is introduced for the path prediction of a system of through-the-thickness cracks and their remaining life assessment for fatigue crack propagation in three-dimensional plate structures. The method is based on a step-by-step finite-element analysis. Crack paths are predicted by the perturbation method applying the local symmetry criterion, which gives a higher-order (curved) approximation of each incremental crack extension as described in Chapters 7, 8, and 9. The finite element re-zoning is automatically carried out, so that user intervention is minimized to generate a very robust mesh during the entire crack propagation process. In Chapter 11, several design concepts are discussed for the prevention of fatigue and fracture in engineering structures, i.e., safe-life design, fail-safe design, and damage-tolerant design. To further improve the structural design against fracture, questions have been raised about whether one may control the crack propagation phenomena to a certain extent based on fracture mechanics, even though fatigue cracks initiate and then propagate. Attempts in this direction are sought by precisely identifying potentially critical locations and the associated failure modes of structural details, predicting crack propagation lives considering the effect of retardation due to load sequence and residual stresses, and predicting crack paths and shapes during crack propagation. This kind of design concept is sometimes called fracture control design, which is discussed in details based on illustrative applications to marine structures.

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