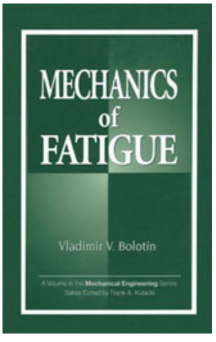

Mechanics of Fatigue

V. V. Bolotin

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This fluent translation of a renowned Russian researcher's work, first published in 1999, has been recently reissued as a keenly priced paperback edition. The 'Introduction' (chapter 1) summarises almost all aspects of classical fatigue theory, where it is taken as read that material fatigue equates to damage caused by repetitive cyclic (dynamic) loading. The author distinguishes between high-cycle and low-cycle fatigue as follows: "If plastic deformations are small and localised, in the vicinity of the crack tip, while the main part of the body is deformed elastically, we have high cycle fatigue". While: ". . . if the cyclic loading produces elastoplastic deformations in the bulk of the body, we have low cycle fatigue"; That is, failure occurs in fewer than 50,000 cycles.

There follows a clear explanation of how microscopic cracks (often visible in aircraft when only 1mm in length) may grow in polycrystalline materials. Several idealised load profiles are shown in figures 1.2, 1.3 and 1.4, and laboratory testing techniques are discussed in section 1.2. Micro and macro aspects of linear and non-linear fracture mechanics are presented in sections 1.6, 1.7 and 1.8, followed by a survey of traditional design methods, such as the cumulative damage rule (section 1.9). Current trends and a synthesis of micro and macro mechanics (sections 1.10 and 1.11) conclude the chapter.

'Fatigue Crack Nucleation and Early Growth' (chapter 2) is skilfully illustrated and mathematically challenging (as are all the chapters throughout the book). Analytical models are devised to predict aspects of fatigue crack nucleation and early growth, the author emphasising that the initial phase of crack propagation frequently accounts for a significant part of the total fatigue life. Suffice it to report that the discourse that follows relies on many pages of mathematics which address phenomenological (scalar) models of crack nucleation, continuum damage mechanics and so forth.

'Mechanics of Fatigue Crack Growth' (chapter 3) refers to the author's early original work in developing the subject (see references 14, 15, 18, 21), but first read/reread the synthesis of micro- and macro-mechanics (section 1.11, page 35) before embarking on the in-depth study of cracked body systems (section 3.2), where the author adopts a critical but always constructive approach to analytical fracture mechanics based on two or three main variables, namely generalised Lagrangrian coordinates and generalised Griffian coordinates and Griffian variations (the latter relating to size, shape and location). The author also recommends the use of the principle of virtual work (section 3.3) for solving multicomponent problems (where more than one independent G coordinate is involved).

The reader should also note, at this stage, that calculations may be purely analytical, iterative and/or statistical in subsequent chapters. However, before that, the reader should read 'Questionary Approximations' (section 3.8), which explains how, when and where A. A. Griffith's approach is applicable in practice.

'Fatigue Crack Growth in Linear Elastic Bodies' (chapter 4) opens by modelling material properties in section 4.1 and then addresses what the author refers to as 'Griffith's problem'. Described by the author as "a modal planar crack in an unbounded elastic plate under remotely uniformly distributed tensile stress", it is illustrated in figure 4.1, culminating in a computational flowchart in figure 4.3, while the author concedes that a large variety of parameters enter equations (4.2)–(4.18) and that feedback iterations are required. The influence of the initial body conditions and crack closure effects are discussed in sections 4.3–4.7, followed by consideration of a differential equation that is verified against a semi-empirical alternative. The effect of micro damage on material properties is covered in section 4.10, and a discussion of numerical results is provided in section 4.11.

Chapter 5 advances the author's deep understanding of the subject by explaining more about crack tip stress distributions, while introducing new issues such as kinking, branching and shape/size effects, the next challenge being to predict crack trajectories using a probability approach (devised by the author). The so-called Monte Carlo numerical simulation method is also considered.

'Fatigue Cracks in Elasto-Plastic Bodies' (chapter 6) explores the effect of plastic straining near the crack tip, raising two concerns, one theoretical and the other practical in nature. The author first shows how linear fracture mechanics theory can legitimately be used to calculate near-crack conditions, without producing the mathematical condition known as a singularity. The author then addresses what at first sight appears to be a paradox, that is: How is it that linear theory produces results that are in good agreement with available experimental data? The author explains what he calls the obvious fact that "[t]he domain of applicability of linear fracture mechanics is (he claims) rather wide", the explanation being that "[t]he crack tip domain is more or less unloaded by the plastic release of stress concentrations". On this basis, the author produces an extensive mathematical analysis of stress/strain distributions for cracks loaded with forces and damage accumulation. The remaining sections cover constitutive relationships, a study of penny-shaped fatigue cracks and the influence of cyclic softening on fatigue crack growth.

'Crack Growth in Hereditary Media' (chapter 7) examines the effect of extraneous inputs such as temperature profiles, corrosion, creep and prior loading histories, crack growth and creep in polymers, being the author's principal concern. The Voight/Maxwell spring–dashpot model, which is widely used to simulate the response of visco-elastic materials, is introduced in section 7.1, and related theory is dispensed in sections 7.2 and 7.3. Crack growth under sustained loading is first considered in section 7.4. followed by a study of sustained and cyclic loading in section 7.5, before 'Fatigue Crack Growth in Polymer Materials' illustrates the effect of crack growth histories, tip radius, crack growth rates and cycle counts in an array of figures (7.15 to 7.20). The remainder of chapter 7 (sections 7.7–7.10) is devoted to creep crack growth. 'Environmentally Affected Fatigue and Related Phenomena' (chapter 8) continues the pursuit of non-mechanical factors such as chemical, electro-chemical, biochemical, moist air and natural water, all of which are known to degrade the strength of materials in general. There follows a fairly lengthy initial discourse on the transport of environmental agents within cracks and how corrosion damage accumulates, leading to stress corrosion cracking and corrosion fatigue. As throughout the book, all major issues are discussed in detail and supported by relevant mathematics. 'Hydrogen Embrittlement and Related Phenomena' (section 8.11) concludes the chapter.

'Fracture and Fatigue of Fiber Composites' (chapter 9) explains how cracks are formed and propagate within fibre-reinforced composites. The author cites work by W. Weibull (1935) and N. H. G. Daniels (1945) and reminds the reader that the study of cracks is strongly probabilistic, but remains confident that the theory already presented is a universal tool, being in the main directly applicable to the analysis of composites. Figure 9.2, which shows the diversity and form of probability density functions for brittle metals and fibre-matrix composites, is surely of interest. Micro damage accumulation in cyclic loading and fracture due to loss of integrity are topics analysed in accord with the author's thoughts on the subject. Microcrack initiation is discussed, from a statistical and practical point of view, in section 9.5, with the author stating that "[w]e must consider various ways to initiate a macro crash", suggesting that the simplest model is a cluster of microcracks. However, that is only one possibility. Cracks in unidirectional fibre composites, the evaluation of fracture work, growth rate diagrams, buckling and stability, delaminations in cyclic compression and bending are further mathematically intense topics to study.

'Fracture and Fatigue in Laminate Composite Structures' (chapter 10) follows a predominantly materials science path, with little being said about the geometry of practical layups. The initial focus is jointly on the study of surface and within-body interlaminate defects, followed by a strongly mathematical consideration of interlaminar fracture work and the balance between active and reactive forces. The high-quality artwork in figures 10.1–10.8 deserves a special mention. Buckling and stability issues which may cause near-surface delaminations are studied in sections 10.4 and 10.5, while the teasing problem of tracking a delamination (as it grows) within a designated elliptical area is tackled mathematically in section 10.6. Interlaminar damage caused by cyclic loading is considered in section 10.7. The section on 'Mechanics of Multilayered Structures', based on a previous book by the author Bolotin and Y. N. Novichkov, *Mechanics of Multilayered Structures* (Mashinostroenye, 1980), more or less brings the current work to a close.

The content of the book may be summarised as follows: the text addresses all aspects of fatigue from a materials science point of view. The author traces the life cycle of cracks from gestation, initiation, propagation to ultimate component failure. The text is highly mathematical and described by the author as a study in analytical fracture mechanics, the core content of which is derived from the synthesis of micro- and macro-mechanics of fatigue – that is at the level of grains, fibres, microcracks and pores. As such, consideration of crystal lattice defects and other metallurgical issues is excluded, prompting the reviewer to recommend G. N. Haidemenopoulos's *Physical Metallurgy: Principles and Design* (CRC Press, 2018) as a companion volume, albeit much more expensive. But this in no way detracts from the value of this highly informative/thought-provoking book.

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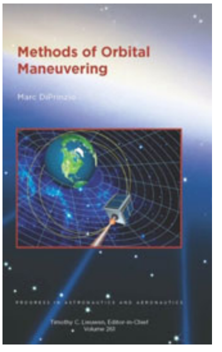

Methods of Orbital Manoeuvring, Progress in Aeronautics and Astronautics series – volume 261

M. Di Prinzio

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