Preface

This book is an attempt to provide a unified methodology to derive models for fatigue life. This includes S-N, ε-N and crack propagation models. This is not a conventional book aimed at describing the fatigue fundamentals, but rather a book in which the basic models of the three main fatigue approaches, the stress-based, the strain-based and the fracture mechanics approaches, are contemplated from a novel and integrated point of view. On the other hand, as an alternative to the preferential attention paid to deterministic models based on the physical, phenomenological and empirical description of fatigue, their probabilistic nature is emphasized in this book, in which stochastic fatigue and crack growth models are presented.

This book is the result of a long period of close collaboration between its two authors who, although of different backgrounds, mathematical and mechanical, both have a strong sense of engineering with respect to the fatigue problem.

When the authors of this book first approached the fatigue field in 1982 (twenty six years ago), they found the following scenario:

1. Linear, bilinear or trilinear models were frequently proposed by relevant laboratories and academic centers to reproduce the Wöhler field. This was the case of well known institutions, which justified these models based on client requirements or preferences. This led to the inclusion of such models and methods as, for example, the up-and-down, in standards and official practical directives (ASTM, Euronorm, etc.), which have proved to be unfortunate.

2. The evaluation of the S-N field lacked models not arising from arbitrary hypotheses. At that time the ASTM (1963) suggested a non explicit certain relation between the statistical distributions of $\Delta\sigma$ for fixed N and N for fixed $\Delta\sigma$.

3. The up-and-down method, clearly inefficient from the cost, reliability and extrapolation to other conditions point of view, was commonly used.

4. The existence of proposals for taking into account the length effect was based on families of distributions, such as the normal, log-normal, etc., that are not stable with respect to minimum operations.

5. The existence of models, which did not contemplate the compatibility condition, led to contradictions and inconsistencies in the cumulated damage evaluations.

6. Models based on micro-mechanical considerations combined with speculative assumptions, but such that they satisfied the compatibility requirements though without an explicit formulation of this very important condition, were unfortunately considered as excessively theoretical and useless for practical application.

7. The ε-N field was treated based on the Morrow linear elastic-plastic model, which apart from depending on a relatively large number of parameters (four) for the reduced information it supplies, only provides the mean curve, thus requiring additional methods to deal with percentile curves.

8. Crack growth appeared as a completely different and unrelated problem to the S-N and the ε-N approaches. While the first was considered as a fracture mechanics based problem, the last two were treated as phenomenological approaches to fatigue of a second order scientific level, and this occurred in spite of the fact that the three problems are different ways of contemplating the same fatigue phenomena.

This book presents a new methodology to build-up fatigue models based first on a practical knowledge of the fatigue problem, combined later with common sense, functional equations and statistical knowledge.

The first chapter provides an overview of the book, and as such, it is a summary of the general ideas present in the book. Reading this chapter should provide some type of reaction from the reader and be a good motivation to continue with the remaining chapters.

In Chapter 2 the S-N or Wöhler field models are discussed and built. To this aim, identification of all variables involved and the Buckingham theorem provide the first and unavoidable steps. Next, the models are sequentially extended, starting from (a) the case of constant stress range and level, continuing with (b) varying stress range and fixed stress level, and finally, ending with (c) varying stress range and level. The main ingredients to cook the models are: the weakest link principle combined with extreme value distribution theory, which leads to Weibull and Gumbel models for case (a), compatibility conditions of the random variables lifetime given stress range, and stress range given lifetime, which leads to straight line and hyperbolas for the percentile curves in case (b), and, finally, compatibility of the S-N fields for constant minimum stress and for constant maximum stress in case (c), leading to a model able to deal with any load. The important result is that the functional form of the models is not arbitrarily assumed, but the result of the conditions to be fulfilled.

In Chapter 3 the length (size) effect is dealt with. Since real structures are much bigger or longer than the laboratory specimens, which necessarily imply reduced sizes, engineers must design them making an important extrapolation. This requires the use of models able to make such a size extrapolation possible.

The weakest link principle together with the concepts of statistical dependence or independence of random variables (lifetimes) allows us to extend the models developed in Chapter 2 to varying lengths. Experimental data permit us to discover that not always is the independence assumption valid.

In Chapter 4 we deal with the ε-N model. Contrary to other approaches that consider this case apart from that of S-N models, and separate the elastic and the plastic components, we integrate both cases and show that the same models developed in Chapter 2 are not only valid for this case, but much more convenient and simpler. A derivation of the S-N curves from ε-N curves is also given in this chapter.

Chapter 5 deals with crack growth models. In contrast to other approaches in which some arbitrary mathematical structure is assumed for the crack growth curves, we derive this structure from fracture mechanics, statistical and common sense considerations, which lead to functional equations providing non-arbitrary models. Two different approaches are given leading to two classes of models, the intersection class of which is derived through compatibility analysis. Finally, the compatibility of the S-N curves model derived in Chapter 2 and the crack growth model derived in this chapter, which are two faces of the same fatigue problem, are used to obtain a model, which allows both approaches to be connected in a beautiful way. To our knowledge this is the first time this connection has been made.

In Chapter 6 we deal with the problem of selecting damage measures. We start by discussing the properties a good damage measure must have. Next, we analyze some alternatives for damage measures and discuss whether or not they satisfy this set of good properties, and conclude with two measures: probability of failure and a normalized measure related to the percentile curves, which are shown to be very simple and useful for measuring damage in fatigue analysis.

Chapter 7 is devoted to the damage accumulation problem. Since the damage measures in Chapter 6 were adequately selected, and the models in Chapters 2 and 5 were designed with damage accumulation in mind, a very simple rule for damage accumulation is provided, together with some illustrative examples.

In Appendix A we have included a short description of classical and some more recent fatigue models selected from those existing in the literature. However, the reader must be aware that the book is devoted to describing a new methodology for building fatigue models, and should have no further expectations in order not to be disappointed.

The proposed cumulative damage models are not intended to reproduce any kind of complex real effects occurring at the crack front, which consideration would be possible only by considering sophisticated numerical calculations and using micro-mechanical and fracture mechanics knowledge. In contrast, the proposed models allow simple approaches to be implemented in a practical fatigue design, similar to those contained in current engineering standards.

Finally, we are grateful for all we have learned during these 26 years from colleagues, students, papers and books. The book is hopefully our way of sharing with the readers all we have learnt from other people, an obligation for all those who were fortunate enough to have access to universities, libraries, journals, books, and the work of others.

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