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FATIGUE STRENGTH AND FRACTURE MECHANICS OF MECHANICAL COMPONENTS

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ABSTRACT

The present paper provides a discussion on all these topics and it offers solutions for it. The authors present an analytical solution of a ΔJ based crack driving force based on an R6 type approach but modified for cyclic loading. The gradual build-up of the crack closure effect is modelled by the so-called cyclic R curve which describes the crack size dependency of the fatigue crack propagation threshold in the short crack regime. It is explained how the cyclic R curve is experimentally determined and how it can be estimated by a modified Kitagawa-Takahashi approach.

Keywords: fatigue strength, S-N curve, crack propagation, J-integral, residual lifetime.

INTRODUCTION

The total life of a component, as well as the fatigue limit, is based on the S-N curve approach. Whilst the material S-N curve is usually determined on smooth specimens (hour glass type or flat plates), component S-N curves, besides the specific material, are affected by a number of factors such as different mean stress, notches, surface roughness and impairments, a highly stressed volume which is different for tension and bending, the size of the component, etc. In practical application, those effects are usually taken into account by semi-empirical correction factors on the fatigue limit.

In contrast, fracture mechanics has the potential for implicitly taking into account all those parameters. The transferability problem from test specimen to component is not solved empirically but on a physical basis. However, in common applications e.g. in the framework of a damage tolerance concept, fracture mechanics is restricted to the determination of a residual lifetime, i.e., the time a pre-existing crack needs to grow to its critical size. The dimensions of the pre-existing crack are defined by the detection limit of the non-destructive testing method applied in quality control after manufacturing or in regular inspections in service. They will usually be in the order of millimeters or - in fracture mechanics terminology - in the order of so-called long cracks.

When fracture mechanics shall be applied to the total lifetime respectively the fatigue limit of components (within the meaning of the S-N curve approach) it has to overcome this limitation. More specifically it has to address four challenges:

(a) It has to adequately describe so-called short crack propagation, which cannot be based on the common long crack concepts for principle reasons. Since the crack size is in the order of the plastic zone size or a notch strain field, the modelling of short crack propagation cannot be based on the common linear elastic ΔK concept. Instead, an elastic-plastic parameter such as the cyclic J integral has to be applied. A second point is that the crack closure concept has to be modified in that the crack opening stress is not a constant, crack size-independent parameter but shows a transient behavior with increasing short crack size.

(b) It has to provide a meaningful definition of the initial crack dimensions as the starting point for an S-N curve relevant (residual) lifetime analysis. This can be based either on the (statistical) size of material defects which can be treated as cracks or by the size of the crack which would arrest subsequent to early crack propagation, whatever is larger.

(c) It has to cope with the problem of multiple cracks for load levels higher than the fatigue limit such as it occurs in many applications in the absence of very large initial defects.

(d) This requires consequent statistical treatment taking into account variations in the local geometry of the area where crack initiation has to be expected as well as the scatter in the initial crack size and in the material data used for the analyses.

RESULTS AND DISCUSSION

The arrest crack size as the initial crack size or a lower bound to this is determined by a cyclic R curve analysis at the stress level of the endurance limit or a suitable substitute. Variations in the local geometry, and based on this, multiple crack propagation require the subdivision of the structure into equal sections the geometry of which is randomly defined but on the basis of realistic statistical distributions of the geometry parameters. The basic scheme for statistically determining endurance limits and finite life S-N curves is shown in Fig. 1.

Because of the high calculation effort it is desirable to have at hand parameter equations for the most important model parameters such as stress-depth profiles, stress intensity factors and others. Such solutions are provided for weldments. Different types of weldments also form the background for illustrating the model of the authors and its suitability for statistically predicting the endurance limit as well as the finite life S-N curve for which a number of examples is provided.

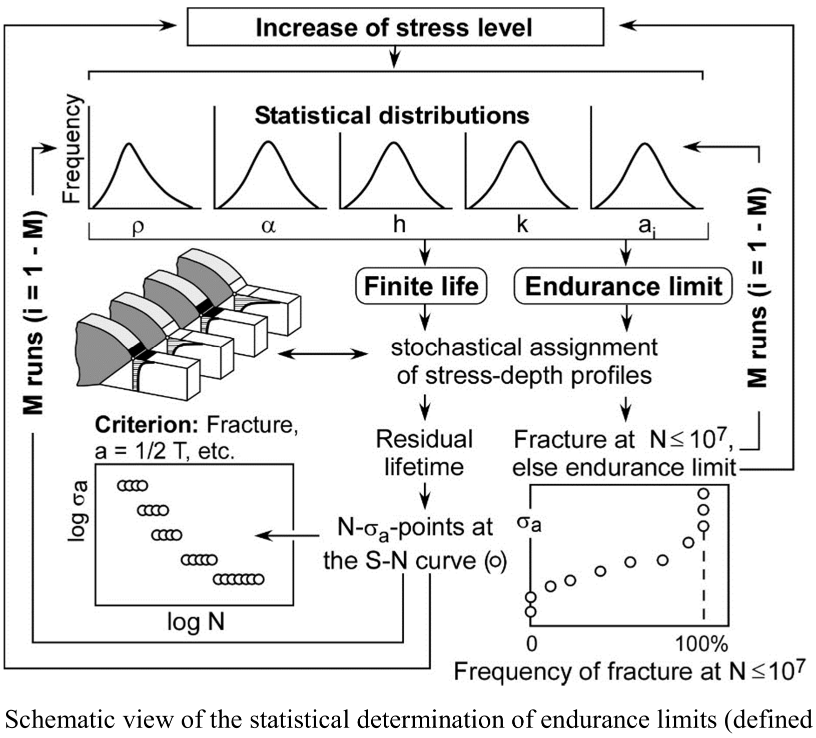

Fig. 1 - Schematic view of the statistical determination of endurance limits (defined for 10^7 loading cycles) and finite life S-N curves.