Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 177 (2017) 526 – 531

Procedia Engineering

www.elsevier.com/locate/procedia

XXI International Polish-Slovak Conference “Machine Modeling and Simulations 2016”

A plastic strain and stress analysis of bending and torsion fatigue specimens in the low-cycle fatigue region using the finite element methods

Peter Kopas*, Milan Saga, Vladislav Baniari, Milan Vasko, Marian Handrik

University of Žilina, Faculty of Mechanical Engineering, Department of Applied Mechanics, Univerzitná 1, 010 26 Žilina, Slovakia

---

Abstract

The assessment of a reliable S-N curve requires an accurate determination of stresses involved. If the stress state is complicated like in a plastic field of deformation the stress for a neck specimen may not always be calculated using formulae available in standard handbooks. Furthermore, the stress may vary from one point to another in a manner which is difficult to predict. This situation arises for instance during bending, torsion and also combined of fatigue specimens loading. In this article a numerical analysis of stresses generated in bending and torsion fatigue specimens has been performed employing the commercially available FEM program ADINA. Computer simulation has been performed on fatigue specimens from high-strength steel DOMEX 700 MC D.

Peer-review under responsibility of the organizing committee of MMS 2016

Keywords: strain; stress; bending; torsion; low-cycle fatigue; finite element methods;

---

1. Introduction

Static or quasistatic loading is rarely observed in modern engineering practice, making it essential to the engineer to implications of repeated loads, fluctuating loads and rapidly applied loads. By far, the majority of engineering design projects involves machine parts subjected to fluctuating of cyclic loads. Such loading includes fluctuating or cyclic stresses that often result in failure by fatigue. The most difficult aspect of fatigue is to detect the progressive changes in material properties that occur during cyclic stressing and the failure may therefore occur with no

---

* Corresponding author. Tel.: +421 41 513 2984; fax: +421 41 565 2940.
E-mail address: peter.kopas@fstroj.uniza.sk

Peer-review under responsibility of the organizing committee of MMS 2016
doi:10.1016/j.proeng.2017.02.256

apparent warning. Also, periods of rest, with the fatigue stress removed, do not lead to any measurable healing or recovery from the effects of the prior cyclic stressing. Thus the damage done during the fatigue process is cumulative and generally unrecoverable [1].

Fatigue failure investigations over the years have led to the observation that the fatigue process actually embraces two domains of cyclic stressing or straining that are significantly different in character, and in each of which failure is probably produced by different physical mechanisms. One domain of cyclic loading is that for which plastic strain occurs during each cycle. This domain is associated with high loads and short lives or low-cycle fatigue. The other domain of cyclic loading is that for which the strain cycles are largely confined to elastic range. This domain is associated with lower loads and long lives, or high cycle fatigue. Low-cycle fatigue is typically associated with cycle lives from one to about 10^4 or 10^5 cycles, and high-cycle fatigue for lives greater than about 10^4 or 10^5 cycles. In recent years, it has been recognized that the fatigue failure process involves three phases. A crack initiation phase occurs first, followed by crack propagation phase and finally, when the crack reaches a critical size, the final phase of unstable rapid crack growth to fracture completes the failure process. The modelling of these phases has been under intense scrutiny, but the models have not yet been developed in a coordinated way to provide widely accepted engineering design tools. The basic premise of the local stress-strain approach is that the local fatigue response of the material at critical point, that is, the site of crack initiation is analogous to the fatigue response of a small, smooth specimen subjected to the same cyclic strains and stresses. The cyclic stress-strain response of the critical material may be determined from the characterizing smooth specimen through appropriate laboratory testing [1, 2].

To properly perform such laboratory tests, the local cyclic stress-strain history at the critical point in the structure must be determined, either by analytical or experimental means. Thus valid stress analysis procedures, finite element modeling or experimental strain measurements are necessary, and the ability to properly account for plastic behavior must be included. In performing smooth specimen tests of this type, it must be recognized that the phenomena of cyclic hardening, cyclic softening and cycle-dependent stress relaxation, as well as sequential loading effects and residual stress effects that may be experienced by the specimen as it accumulates fatigue damage are presumed to be the same as at the critical point of the structure member being simulated. Since, including all these factors in a test is inconvenient, inaccurate and expensive, the use of finite element method has become a powerful tool to calculate the cyclic stress-strain response of any structure or mechanical component. The finite element method is especially used in the ground vehicle industry where discontinuities of the geometry such as notches and holes produce difficulties to calculate the local cyclic stresses and strains, which are essential to predict the fatigue life of any structure or component [3, 4].

2. Strain-life approach

The strain-life method is based on the observation that in many components the response of the material at critical locations is strain or deformation dependent. When load levels are low, stresses and strains are linearly related. Consequently, in the elastic range, load-controlled and strain controlled test results are equivalent. At high levels, in the low-cycle fatigue regime, the cyclic stress-strain response and the material behavior are best modelled under strain-controlled conditions. In the strain-life approach, the plastic strain or deformation is directly measured and quantified. As discussed previously, the stress-life approach does not account for plastic strain. At long lives, where plastic strain is negligible and stress is easily related to strain, the strain-life and stress-life approaches are essentially the same [5, 6].

Although most engineering structures and components are designed such that the nominal loads remain elastic, stress concentrations often cause plastic strains to develop in the vicinity of notches. Due to the constraint imposed by the elastically stressed material surrounding the plastic zone, deformation at the notch root is considered strain-controlled. The strain-life method assumes that smooth specimens tested under strain-control can simulate fatigue damage at the notch root on an engineering component. Equivalent fatigue damage is assumed to occur in the material at the notch root and in the smooth specimen when both are subjected to identical stress-strain histories. As seen in Fig. 1, the laboratory specimen models an equally stressed volume of material at the notch root [3, 7].

Crack growth is not explicitly accounted for in the strain-life method. Rather, failure of the component is assumed to occur when the equally stressed volume of material fails. Because of this, strain, strain-life methods are