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Abstract

Metals used in industry for structures and aero-engine components are sometimes subjected to very high cycle fatigue (VHCF) damage during their working service. In this paper, a novel method is presented to determine the size and location of a circular crack located within a metal specimen under 20 kHz VHCF loading conditions. The method is based on an analysis of the temperature rise on the surface of the specimen and correlation of this temperature rise to the energy dissipation in the plastic zone of the crack. The approach taken is to first determine the heat source location and strength using an inverse heat transfer calculation based on the surface temperature measurements. Next, the relationship between the heat and the material hysteresis loop in the plastic zone, which is a function of stress intensity factor and vibration amplitude cyclic loading of the specimen, is found. The calculation of the stress intensity factor under vibrational loading is often an obstacle in VHCF research because there is currently no standard or existing formula. In this paper a general polynomial formula for the stress intensity factory under 20 kHz loading conditions is obtained using a finite element modeling approach as a function of the specimen's material properties and position and size of the internal crack.

Key words: VHCF, Inverse heat transfer method, Stress intensity factor, Plastic zone

1. Introduction

In the early 1990's, Bathias [1] demonstrated that metals fail due to very high cycle fatigue (VHCF) when subjected to more than 10^{10} cycles. Many materials, including some steels and cast irons, exhibit a sharp decrease in fatigue strength when subjected to between 10^6 and 10^{10} cycles. This behavior is in contrast to the classical fatigue strength limit, below which a material is assumed to have an infinite life. Current theories are not able to properly describe the degradation of a material's fatigue strength in the VHCF regime, and the prediction of material properties and component lifetimes are often determined from experimentation.

Internal friction produced within a material during cyclic loading results in the generation of several energy forms including elastic strain energy, plastic strain energy, and inelasticity and heat generation and dissipation [2-4]. Ultrasonic experiments have demonstrated that energy generation and dissipation in the VHCF regime results in an increase of temperature of the test specimen. Even in the cases of confined plasticity or micro plasticity, the heat generation and dissipation is not negligible. The heat generated and transmitted within the material during high cyclic loading depends on a number of factors including mechanical deformation, stress amplitude, and loading frequency. In other words, VHCF damage depends on complicated energy dissipation processes that are not yet fully understood.

For materials with inclusions, the crack initiation site may be internal to the specimen and acts as a heat source within the material during high cyclic loading conditions. The dissipated energy (DE) from the internal crack site can be identified by the temperature evolution of the specimen. The heat generated from internal circular cracks results in a temperature field on the surface of a specimen called a "fish eye formation". Fish eye formations have been observed during VHCF loading experiments when the number of cycles increases beyond 10^7 cycles Bathias [1]. The model developed by Paris for fish eye formation in the gigacycle fatigue regime demonstrated

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