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Investigation of Energy Dissipation and Plastic Zone Size during Fatigue Crack Propagation in a High-Alloyed Steel

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Abstract

During fatigue crack propagation experiments on a high alloyed steel under fully reversed loading conditions lock-in thermography measurements have been undertaken. The E-phase images of the thermography measurements were used to determine the size of the plastic zone. As expected, the measured plastic zone sizes are increasing with the stress intensity factor and were found to be independent of the crack length. Surprisingly a decrease of the crack propagation rate in experiments performed with a constant stress intensity (K_{max}=const. and ΔK=const.) was observed. With increasing crack length the thermographic measurements showed an increase of the dissipated energies measured in front of the crack tip. These increasing dissipated energies in front of the crack tip seem to be responsible for the decrease of the crack propagation rate. The energies dissipated in front of the crack tip don't directly correspond with the size of the plastic zone.

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Keywords: Fatigue; crack propagation; thermography

1. Introduction

Lock-In thermography is a well-established technique for measuring elastic stresses under cyclic loading (Harwood et al (1991)). Beside elastic stresses dissipative energies and thereby plastic deformation can be analyzed as shown by Brémond (2007). Therefore this method can be used to investigate the plastic zone of fatigue cracks. In this work the plastic zone and the energies dissipated during fatigue are investigated in a high alloyed steel.

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2. Experimental Details

2.1. Crack Propagation Experiments

The experiments were undertaken with specimens of a high-alloyed steel (X5CrNi18-10, AISI 304) sheet material with a thickness of 4 mm. The SEN-specimens with a length of 80 mm and a width of 12 mm were produced from the sheet material. A starter notch with a length of 1 mm and a notch radius of 0.25 mm was machined into the specimens. In a distance of 4 mm symmetrical to the notch two pins for potential drop measurement have been mounted into the specimens (Fig. 1).

The fatigue tests have been performed under fully reversed loading conditions at a frequency of 20 Hz using a servo-hydraulic testing machine with a DOLI EDC 580 controller. The machine is equipped with a specimen chamber and fixed grips to minimize bending forces (Fig.1). A detailed description of the equipment and the test methods are given by Bär and Volpp (2001).

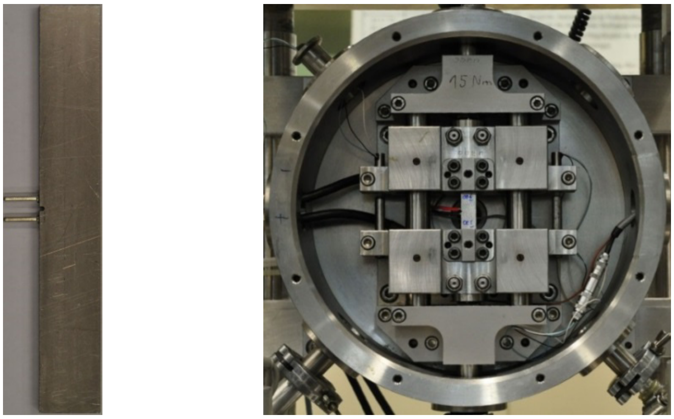

Fig. 1. SEN-specimen with pins for potential measurement and specimen chamber with fixed grips.

For crack length measurement the DC potential drop method was used. Therefore, a constant current was conducted through the specimen. The potential drop was measured between the two pins close to the notch of the SEN-specimen using an amplifier of the EDC 580 control electronics. The software allowed a calculation of the crack length and therefore the stress intensity during the experiment. This provides the possibility to control the stress intensity during the experiments and to perform experiments with constant stress intensity K_{max} and ΔK.

2.2. Thermographic measurements

The fatigue crack propagation experiments were accompanied by thermo elastic stimulated lock-in thermography. This method uses the thermoelastic effect for cyclic thermal stimulation. The investigations have been performed with a Cedip Titanium HD 560 camera and the software Altair LI. For analysis the software Altair LI delivers two different modes: the E-mode and the D-mode. The E-mode is based on the thermo elastic effect and can therefore be used for stress analysis as shown in Harwood et al (1991). The D-mode provides information about the dissipated energy as shown by Brémond (2007). With the integrated lock-in module it is possible to calculate the resulting amplitude of temperature variations (amplitude image) and the distribution of phase lags between the thermographic signal and the mechanical loading (phase image) for the E-mode and D-mode, respectively. As shown by Sakagami et al (2005) the D-Mode images can be achieved when the evaluation is performed with the double loading frequency. During the crack propagation experiments amplitude and phase images in the E- and D-Mode were received from lock-in evaluations which were performed automatically in a defined interval. To enhance the emissivity of the specimen the surface was coated with a thin graphite layer.