STRUCTURAL HEALTH MONITORING OF FATIGUE BEHAVIOR FOR Ti ALLOYS BY DATA ASSIMILATION OF AE

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Abstract
The main purpose of this research is to develop a structural health monitoring method for fatigue behavior of Ti alloys. Experiments were conducted on the effect of microstructure on fatigue behavior at room temperature. Analysis of fracture and deformation behavior using finite element method simulation was also performed. Resutls of AE measurements during fatigue crack initiation and propagation was used to assimilate the mechanical informations using data science methods. For example, a method to directly predict the crack growth rate with variance from the AE measurement results was developed.

1. Introduction

The AE (acustic emission) method is widely applied in industry as one of the effective non-destructive inspection techniques for detecting damage with high sensitivity. It is possible to analyze AE waveforms by applying methods developed in seismology. However, it is difficult to analyze quantitatively because the wave propagation behavior is greatly affected by the shape of the structure due to the unique reflection characteristics of ultrasonic waves. In addition to material engineering knowledge, a wide range of engineering knowledge is required, including ultrasonic vibration theory, hardware for realizing high-speed measurement, and software for analyzing waveforms. The authors have been working on the detection of microscopic fractures occurring in various materials by AE analysis for many years [1]. Recently, the room temperature fatigue mechanism of various alloys including Ti-6Al-4V alloy was also studied[2]. Based on the crystal plasticity analysis (CPFEM) method, a research framework was developed to integrate experiments and numerical calculations for clarifying and prediction fo the high-cycle fatigue behavior for Ti-6Al-4V alloys[3]. In this study, the effect of material microstructure on room temperature fatigue behavior was investigated, and the analysis of fracture and deformation behavior using the crystal plasticity finite element method was also investigated. By combining the AE measurement results generated by microscopic phenomena associated with fatigue using data science methods, a method for directly predicting physical quantities from the AE measurement results was developed and verified in fatigue tests for several Ti alloys.

2. Method

Acquisition and analysis of AE signals of material deformation/fracture were carried out by utilizing various AE measurement techniques cultivated so far and incorporating data science methods. In the analysis, it was aimed to realize an inverse analysis method that predicts the optimal model from the measurement data by a data-driven approach, that is, applying the latest machine learning methods such as sparse modeling and data assimilation based on Bayesian inference. A model for fatigue life prediction with AE data was developed by establishing empirical relationships between AE parameters (amplitude, rise time, count rate and so on) and local strain or fatigue crack growth rate. Bayesian statistical model selection by Markov Chain Monte Carlo (MCMC) was used to find the optimal model[4]. This procedure was applied to the fatigue behavior analysis of pure fatigue tests and dwell-fatigue tests at room temperature. The local strains and crack lengths were obtained experimentally and also derived from calculation results. Also an analysis based on the assumption that AE events follow a stochastic process was performed as a model for detecting change points in the fatigue process. AE data were analyzed to detect changes in mechanism, such as changes from short crack to long crack growth. With this framework, a strain accumulation or crack propagation model was proposed based on AE measurements that enables real-time monitoring of the damage formation process under various fatigue conditions at room temperature as one of structural health monitoring tools.

3. Results

Figure 1 shows an example of the strain accumulation results during dwell-fatigue tests of Ti-6Al-4V alloys which was predicted by AE through Bayesian inference-based algorithms. Strain accumulation was well predicted by the empirical model of AE data. Figure 2 shows the another example of the prediction of the crack growth rate of Ti-6Al-V alloys with different microstructures using the particle filter method. The accuracy of the predictions tended to increase as the number of cycles increased. However, a noticeable variation in the prediction strogly depends on the microstructure type and grain size.

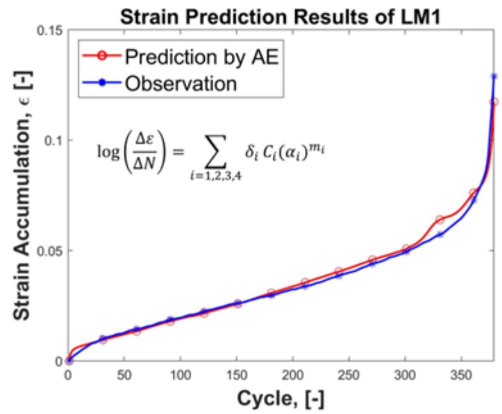

Fig. 1 Strain accumulation prediction results by AE during dwell-fatigue test on Ti-6Al-4V alloys with fully lamellar microstructure

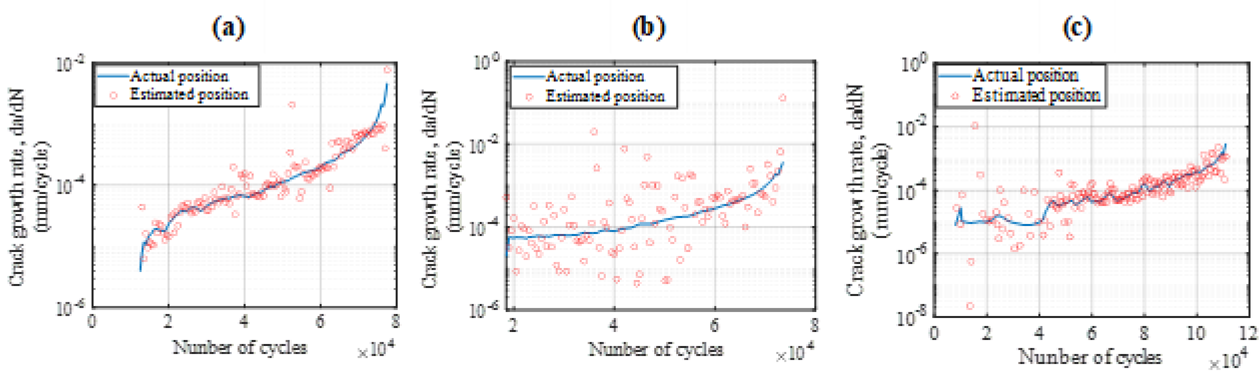

Fig. 2 Comparison of predicted and experimental crack growth rates (a) bimodal microstructure with small grain size, (b) bimodal microstructure with small large size, (c) lamellar microstructure.

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