Mechanical Engineering Doctoral Defense

Characterization of Fatigue Damage in Aerospace Materials under Complex Multiaxial Loading

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abstract

Multiaxial mechanical fatigue of heterogeneous materials has been a significant cause of concern in the aerospace, civil and automobile industries for decades, limiting the service life of structural components while increasing time and costs associated with inspection and maintenance. Fiber reinforced composites and light-weight aluminum alloys are widely used in aerospace structures that require high specific strength and fatigue resistance. However, studying the fundamental crack growth behavior at the micro- and macroscale as a function of loading history is essential to accurately predict the residual fatigue life of components and achieve damage tolerant designs. The issue of mechanical fatigue can be tackled by developing reliable in-situ damage quantification methodologies and by comprehensively understanding fatigue damage mechanisms under a variety of complex loading conditions. Although a multitude of uniaxial fatigue loading studies have been conducted on light-weight metallic materials and composites, many service failures occur from components being subjected to variable amplitude, mixed-mode multiaxial fatigue loadings. In this research, a systematic approach is undertaken to address the issue of fatigue damage evolution in aerospace materials by:

(i) Comprehensive investigation of micro- and macroscale crack growth behavior in aerospace grade Al 7075 T651 alloy under complex biaxial fatigue loading conditions. The effects of variable amplitude biaxial loading on crack growth characteristics such as crack acceleration and retardation were studied in detail by exclusively analyzing the influence of individual mode-I, mixed-mode and mode-II overload and underload fatigue cycles in an otherwise constant amplitude mode-I baseline load spectrum. The micromechanisms governing crack growth behavior under the complex biaxial loading conditions were identified and correlated with the crack growth behavior and fracture surface morphology through quantitative fractography.

(ii) Development of novel multifunctional nanocomposite materials with improved fatigue resistance and in-situ fatigue damage detection and quantification capabilities. A state-of-the-art processing method was developed for producing sizable carbon nanotube (CNT) membranes for multifunctional composites. The CNT membranes were embedded in glass fiber laminates and in-situ strain sensing and damage quantification was achieved by exploiting the piezoresistive property of the CNT membrane. In addition, improved resistance to fatigue crack growth was observed due to the embedded CNT membrane.

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