Abstract

This PhD dissertation investigated the challenges associated with the thermomechanical fatigue response and structural integrity of PMCs by incorporating the self-heating phenomenon into the analysis through a series of in-depth studies, resulting in five main contributions.

The first key contribution of this dissertation was the development of a physics-based framework for modeling the self-heating effects in the fatigue-loaded PMCs. This framework enabled the simulation of temperature distribution through the thickness of PMCs, which cannot be directly measured using an IR camera. The second key contribution of this research was the establishment of a novel unitless and scalable factor based on the heat dissipation rate concept. This factor served as a bridge for transferring fatigue results from UFFT (20.2 kHz) under controlled temperature using a pulse-pause loading pattern with forced air cooling to LFFT (50 Hz) under natural air cooling. Furthermore, the scope of the heat dissipation rate concept was broadened and utilized for determining the critical self-heating temperature interval within the UFFT scenario, which can serve as a failure criterion for future ultrasonic fatigue testing. The third key contribution of this research was the determination of FFE values within different fatigue regimes (LCF, ICF, and HCF) by combining IAT and CAT results. The FFE-based S-N curves were then established and validated against the standard S-N curves at the final failure of PMCs. The EDI-, and SD-based S-N curves were further established for assessing the fatigue damage evolution. These approaches allowed for monitoring the continuous fatigue-induced degradation process, from the early stage of damage initiation to the final failure, overcoming the limitations of standard S-N curve-based assessments.

The fourth key contribution of this research was the assessment of the capability of thermally conductive nanocarbon-based allotropes in mitigating the thermal responses induced by the self-heating phenomenon. This allowed for controlling the self-heating temperature effectively, thereby prolonging the life of modified PMCs within different fatigue regimes.

The final key contribution was extending the use of SHVT for non-destructive evaluation of 2D PMCs and developing a two-step algorithm based on the concepts of the boundary of effective thermograms, and the maximal temperature ratio. This algorithm allowed for methodically selecting the optimal raw thermogram from a large set for each damage scenario.