FATIGUE CHARACTERIZATION OF ADHESIVELY-BONDED GFRP JOINTS VIA SELF-HEATING

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Abstract

High cycle fatigue (HCF) of composite structures is known to exhibit self-heating coupled with stiffness degradation due to progressive damage accumulation. Recent advances have been made in correlating fatigue damage accumulation to full-field temperature fields during the HCF of composite structures. This work uses a thermal medium wave infrared camera to quantify self-heating in adhesively bonded unidirectional glass fiber reinforced polymer (UD-GFRPs) specimens under tension-tension fatigue loading.

1. Introduction

Composites subjected to cyclic loading manifest self-heating concomitant with the structure's degradation in mechanical properties. The current work investigates the self-heating effects of adhesively-bonded UD-GFRP joints with different thicknesses of the adhesive at a fatigue loading frequency of 5 Hz. The specimens comprised of 4-layers of unidirectional glass fiber fabric with 0.019 in thickness from Vectorply Corporation as reinforcement and epoxy Westlake RIMR135 resin as the matrix with BPR135G3/BPH135G system as the adhesive bond paste, consistent with wind turbine blade applications. The specimens were tested using a 100 kN MTS servo-hydraulic system (Landmark Model 370.10) under tension-tension fatigue with a staircase loading maintaining a load ratio of R = 0.1 (see Fig. 1, 2). Unlike the typical stress-life approach, infrared thermography (IRT) based fatigue uses staircase loading for the specimen, spanning various load levels on the same specimen. The specimen temperature at each load step stabilizes after a few thousand cycles. A step size of 4000 cycles has been chosen in the current test. Since the self-heating phenomenon occurring in FRPs is primarily a matrix-dominated phenomenon due to viscous dissipation occurring in the polymer, the value of the stabilized temperature at each load level depends on the loading frequency, matrix volume fractions, matrix composition, porosity, etc. For adhesive joint applications, the type of adhesive and surface chemistry also plays a key role in the temperature maps. The specimens were loaded to failure, and the temperature change at regular intervals was recorded. A high-performance infrared camera (Micro-epsilon thermoIMAGER TIM QVGA) with 18° lens (optical resolution: 382×288 pixels) and 100 mK high-temperature sensitivity was used for all the experiments. The loading cycle and the experimental setup can be seen in Fig. 1 and Fig. 2.

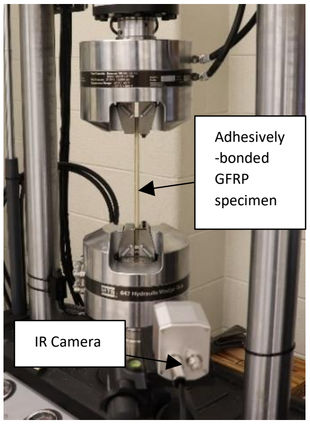


Fig. 1 – Experimental setup

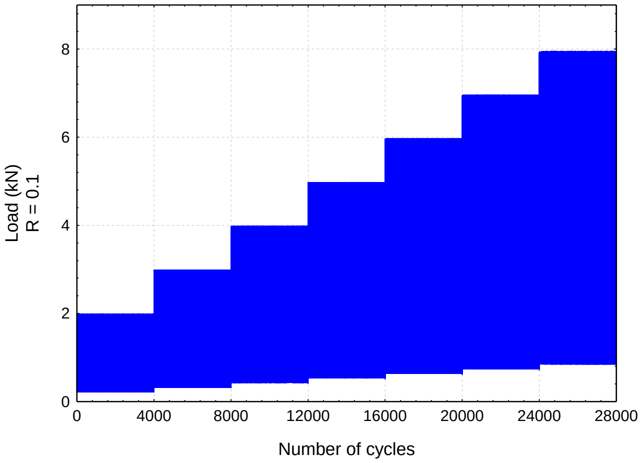
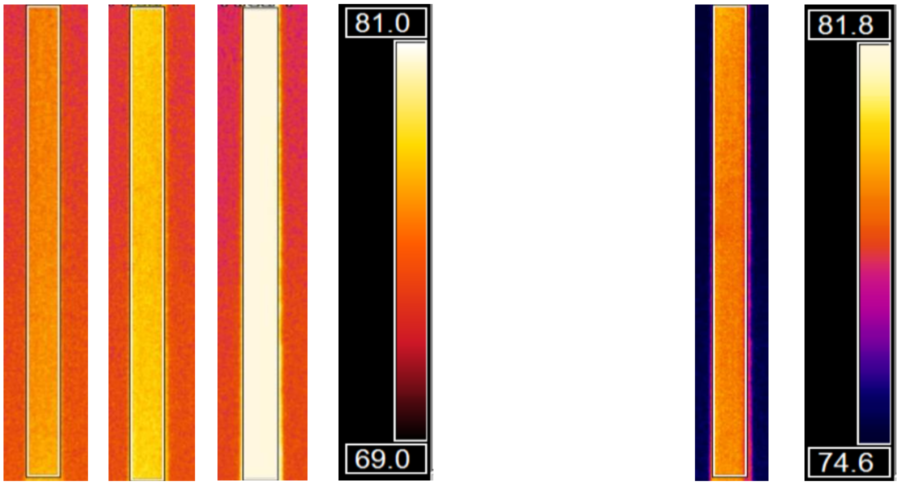


Fig. 2 - Loading cycle for the fatigue experiment



(a) (b) (c) (d)

Fig. 3 – Maximum surface temperature (in ˚F) of the specimen at the end of a) 4400 cycles, b) 14000 cycles, c) 28000 cycles d) Rescaled legend showing the temperature difference between the adhesive and adherend at the end of 28000 cycles

2. Results

Figure 3 depicts the full-field temperature maps of the adhesive joint measured along the UD-GFRP (adherend) surface during fatigue testing at three different load cycles. As can be observed, the surface temperatures were found to increase with increasing load cycles.

Approximately a 4°F increase in surface temperature at the end of 28000 cycles was observed for the adhesive joint. A careful examination of the adhesive joint shows a clear delineation between the adherend and adhesive temperatures with increasing load cycles (see Figure 3 (d)). The surface temperatures are found to stabilize at every load step. Examining the stabilized cyclic temperatures as a function of applied stress magnitudes is ongoing.

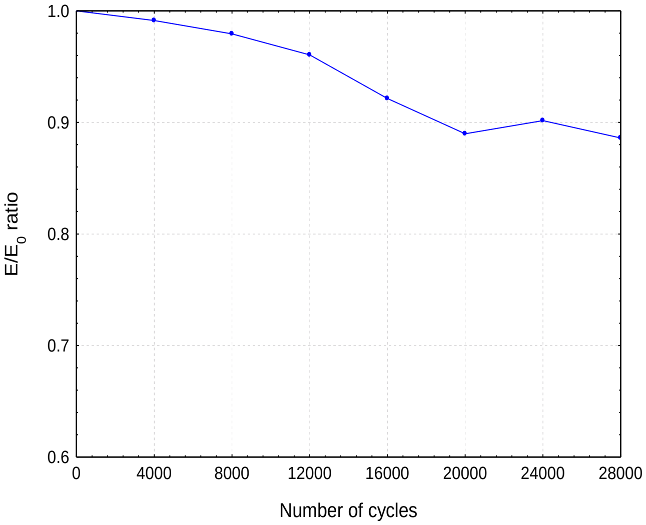


Fig. 4 –Stiffness degradation with respect to number of cycles (Y-axis rescaled to start from 0.6)

The observed changes in the cyclic stabilized temperatures with increasing load cycles are coupled with the specimen's stiffness degradation, indicative of the cumulative damage in the specimen (see Fig. 4). Fig. 4 suggests additional load-carrying capability for the specimen. Further cyclic loading tests are ongoing.

3. Conclusions

Self-heating behavior has been used to characterize the fatigue behavior of adhesive joints in the current work. Efforts are underway to understand self-heating fundamentally by developing specific test configurations with varying adhesive/adherend thicknesses. A correlation between surface temperatures, cumulative damage, specific damage modes, and load-carrying capability of the adhesive joint is sought.