RAPID FATIGUE CHARACTERIZATION OF ADDITIVELY MANUFACTURED POLYMER COMPOSITES USING INFRARED THERMOGRAPHY

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Abstract

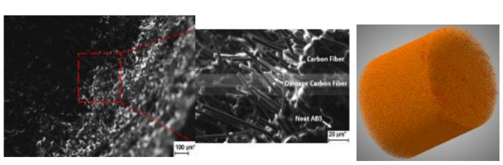
High cycle fatigue (HCF) in composite structures leads to damage accumulation and associated stiffness degradation, which are challenging to quantify. This work uses a medium wave infrared to monitor self-heating in chopped carbon fiber/acrylonitrile butadiene styrene specimens subjected to tension-tension fatigue loading. An innovative rapid testing protocol that correlates the generated full-field temperature maps and stiffness degradation data has been developed providing a comprehensive understanding of material behavior under cyclic loading. Results contribute to the fundamental understanding of HCF in composite materials and develop more accurate predictive models for fatigue life. Rapid testing has allowed correlating process parameters with the microstructure and structural integrity of additively manufactured (AM) composites.

1. Introduction

This study focuses on investigating the self-heating effects of chopped carbon fiber /acrylonitrile butadiene styrene (ABS) specimens (as shown in Figure 1) under cyclic loading, produced using Additive Manufacturing-Compressive Molding (AM-CM), a novel process developed by Oakridge National Lab [Vipin Kumar, Additive Manufacturing, https://doi.org/10.1016/j.addma.2020.101733]. AM-CM composites tend to have lower porosity compared to other traditional AM processes. Specifically, the study examines the self-heating effects of CF/ABS at a fatigue loading frequency of 15 Hz under tension-tension fatigue using a 100 kN MTS servo-hydraulic system (Landmark Model 370.10) with a staircase loading maintaining a load ratio of R = 0.1.

Unlike the traditional stress-life approach, this study uses an infrared thermography (IRT) based fatigue testing method with a staircase loading that spans various load levels on the same specimen. The stabilized temperature at each load level depends on several factors, including loading frequency, matrix volume fractions, matrix composition, porosity, fiber aspect ratio, fiber orientation, and viscous dissipation occurring in the polymer. The temperature change at regular intervals is recorded using a high-performance infrared camera (Micro-epsilon thermoIMAGER TIM QVGA) with an 18˚ lens and 100 mK high-temperature sensitivity.

The experimental setup and loading cycle are shown in Figure 2 and Figure 3, respectively. This study's results may help improve the understanding of the behavior of composite structures under cyclic loading and develop more accurate predictive models, which could ultimately lead to the design of more reliable and durable composite structures.



a) b)

Figure 1- a) SEM image showing fiber distribution b)Micro-CT image

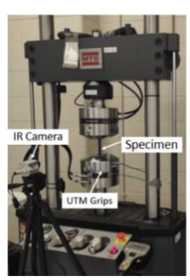


Figure 2 - Experimental setup

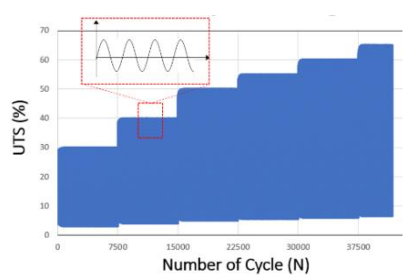


Figure 3- Staircase loading for fatigue testing

2. Results

Figure 5 shows the full-field temperature maps of the specimen measured along the surface during fatigue testing at three different loads. It can be observed that the surface temperatures increased with increasing load cycles. The given specimen showed an approximately 12°F increase in surface temperature at the load of 65% UTS. As seen in Figure 7, the surface temperatures stabilized at every load step.

During testing with increasing load cycles, stiffness degradation was monitored, indicative of the cumulative damage in the specimen and coupled with the observed changes in the cyclic stabilized temperatures (refer to Figure 4). A rest time was introduced after every load step to attain room temperature.

Three process parameters were tested using the rapid IRT approach to obtain fatigue limits through bilinear curve fitting. The results showed that increasing fiber content led to increasing fatigue limits. However, surface characteristics played a major role in determining life, as seen in Figure 6.

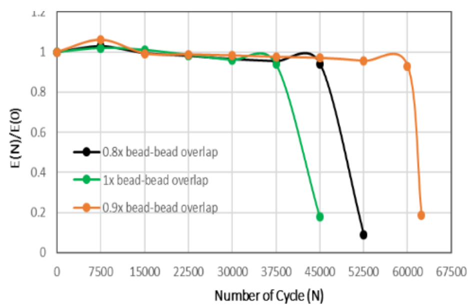


Figure 4- Stiffness degradation over loading cycles

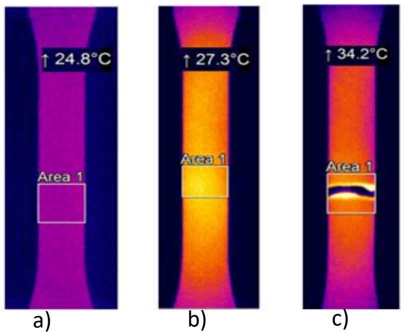


Figure 5- Maximum surface temperature (in ˚F) of the specimen at the a) No Load, b) 60% UTS, c) Failure stage

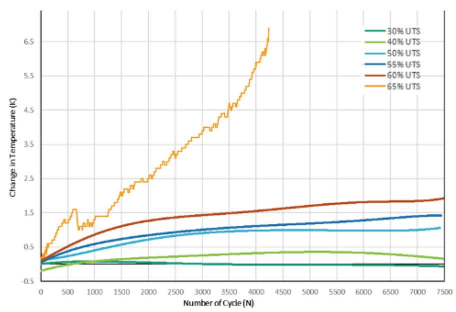


Figure 7- Change in Temperature over Cycles

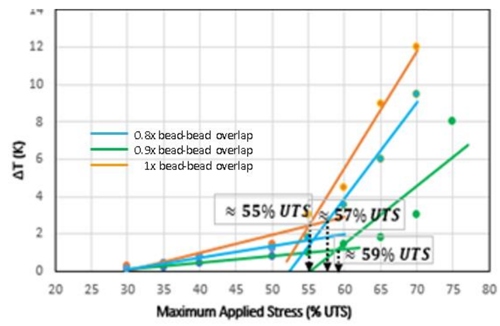


Figure 6- Bilinear stress curve for temperature change

3. Conclusions

The current study employed self-heating behavior to characterize the fatigue behavior of composite materials. The findings demonstrate that IRT is a reliable and efficient technique for rapid quantification of the fatigue life of composites. The observed improvements in stiffness and delayed fiber splitting resulting from the presence of chopped fibers acted as effective barriers to fatigue crack propagation, enhancing the composites' fatigue strength. These results offer valuable insights into using self-heating behavior and IRT as an effective methodology for future research and development of advanced composite materials.