Thermal-mechanical-chemical coupled model and three-dimensional damage evaluation based on computed tomography for high-energy laser-ablated CFRP

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Abstract

High-energy laser is widely used for machining carbon fiber reinforced polymer (CFRP) composites because of their high precision and fine quality. However, the mechanism by which CFRPs are damaged by high-energy laser in processing is unclear. In this research, the coupled mechanism of laser-ablated CFRPs is investigated experimentally and theoretically. The three-dimensional morphology of laser-damaged CFRPs is captured by computed tomography (CT), which quantitatively characterizes the degree of charring and internal delamination. Accordingly, a thermal-mechanical-chemical coupled model is established considering the matrix pyrolysis, pyrolysis gases flow, sublimation of the charring layer and mechanical failure. The progressive loss of solid media and the inhomogeneous deformation of CFRPs are incorporated into the traditional ablation kinetic model, making it possible to describe the damage to CFRPs caused by both chemical reactions and thermal stress. The predicted damage morphology is consistent with the experimental results, revealing the generation of internal defects due to the synergistic effects of interlaminar tensile stress and matrix pyrolysis. Additionally, the effects of charring layer sublimation, laser power density and process time on damage responses are analyzed, and the real-time evolution of damage degree is investigated.

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