
Post-fire fracture behavior of hybrid PEEK thermoplastic composite laminates under one-sided kerosene flame aggression: Experimental and numerical analysis

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Abstract

With regard to the stringent fire safety regulations for thermoplastic-based (TP) composites in aeronautics field (1), it is a critical issue to understand and quantify the fracture mechanisms of degraded laminates, whose behavior is highly heterogeneous and anisotropic (2). Most of the attention has been given to unidirectional (UD) thermosetting laminates (3). Therefore, this study aims at investigating the influence of different kerosene flame exposure time on both the thermally-induced damages and the post-fire fracture behavior of hybrid woven-ply carbon/glass fibers reinforced PolyEther Ether Ketone (CG/PEEK) laminates. In the present work, the pyrolysis behavior of CG/PEEK composites subjected to one-sided fire exposure is explored by experimenting on a burner bench (4). The Compact Tension (CT) specimens are exposed to kerosene flame (116 kW/m² and 1150°C) with exposure time ranging from 5 min to 15 min. The mechanical tests are then conducted to evaluate the residual fracture toughness of laminates at room temperature. Fractographic analysis has been carried out by means of microscopic and tomographic observations using a numerical optical microscope Keyence VHX-5000 and RX Solutions EasyTOM-150 respectively to visualize, classify and quantify the thermally-induced damages along with the translaminal fracture under mechanical loading (5). Using a Digital Image Correlation (DIC) system combined with a binarization algorithm (6), the crack tip is located via the discontinuity of the strain field resulting from the crack propagation within material during loading. Here, the ASTM-399 test standard (7) is applied to determine the value of the critical strain energy release rate (SERR), from the application of the compliance method to the force-displacement data during crack propagation.

Under flame exposure, the microstructure observations show a heterogeneous distribution of damages associated with a significant temperature gradient within the laminates. Depending on the pyrolysis degree of each ply, the load bearing capabilities of the plies gradually deteriorate from the exposed to the opposed side. The two regions (named char and

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decomposition regions) characterized by different thermally-induced damage states do not take up the mechanical loading the same way, the most tensile loading being born by region with less damage. The critical fracture toughness (FT) values shows a decreasing trend (as a function of fire exposure time) with increasing ply number of the charred region through the thickness. FT tends to slightly increase during crack propagation in each case, which is attributed to fiber bridging occurring in the char region (characterized by a weak interface), and secondary cracks occurring within the char region that may prevent the compliance method to be relevantly applied.

The correlation between post-fire residual mechanical properties and thermally degraded regions is further investigated, with the implementation of an analytical model (8) based on the porosity content ratio of each region, to better account for the coupling between fracture behavior and critical service conditions (under fire). A numerical model implemented in the FE code Abaqus/Explicit is used to simulate the translaminar fracture and the damage propagation resulting from fiber breakage in CG/PEEK laminates. Based on CT testing data, the model accounts for the translaminar fracture in opening mode (mode I) due to fiber breakage. Ultimately, the proposed model enables a better understanding of the role played by the mechanical response of each ply along with the PEEK matrix pyrolysis on the tensile translaminar fracture behavior of woven-ply laminates after kerosene flame exposure.

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