Comparative study on the residual flexural behavior of woven-ply reinforced thermoplastic or thermosetting laminates exposed to a hydrogen/oxygen flame

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Abstract

The current environmental crisis (CO2 emissions and energy demand) reveals that two of the main issues in aeronautics are the light-weighting design (1) and the development of hydrogen combustion aircrafts (2). To respond to the light-weighting concern, the integration of polymer matrix composites in structural parts is increasing. However, their behavior depends significantly on their working conditions due to their polymer matrix. In particular, the fire issue is a primary concern for aircraft manufacturers. Therefore, understanding and characterizing the thermomechanical properties of composite under critical conditions (fire) is essential (3). Previous works have investigated the (residual) mechanical properties in tension and compression of composite materials after exposure to a kerosene flame (flame at 1100◦C and heat flux of 116kW/m^2) (4), (5). Regarding the mechanical consequences of an exposure to a hydrogen/oxygen flame, very few analyses have been presented so far (6) and different questions remain open, besides the differences in input energy that a hydrogen/oxygen flame can provide (200 to 800kW/m^2, versus 116kW/m^2 with kerosene), the thermal transfers and the involved physics depend on the nature of the fuel. Both, a hydrogen/oxygen flame and a kerosene flame result in the formation of a carbonaceous char layer. However, a hydrogen combustion produces about 2.6 times more water vapor than a kerosene one (7), which is suspected to affect char formation. In ref. (6), the residual tensile behavior of CG/PEEK was investigated after a 5 minutes exposure to a hydrogen/oxygen flame (flame at 2000◦C and heat flux between 200kW/m^2 and 800kW/m^2). The mechanical properties in tension were correlated with the applied heat flux: the axial strength and stiffness were equal to 0 for the highest heat flux (600kW/m^2 and 800kW/m^2), whereas the decrease was moderate after an exposure to 200kW/m^2 heat flux (-35% for strength and -60% for stiffness). These reductions in tensile properties could be explained by the delamination of the specimens, which affects their structural integrity. For the highest applied heat flux,

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X-ray tomography showed a severe delamination of the plies near the back surface. During the tensile tests, the transverse compressive load applied by the grips of the tensile machine resulted in the bucking of these plies and the loss of the structural integrity of specimens before even starting the tensile test. The impact of thermal degradation (interply delamination) on the residual mechanical properties would be more critical for a different loading such as a bending test where the interfaces between the plies play a major role.
This study investigates the thermomechanical behavior of three polymer matrix composites that differ only in the nature of the polymer: 5-harness satin weave carbon fiber fabric for all, polyetheretherketone (PEEK), polyphenylene sulfide (PPS) or epoxy for the matrix. Rectangular plates of 100x150mm^2 were exposed to a hydrogen/oxygen flame at the temperature of 2000$\circ$C and with a heat flux of 400kW/m^2 for different durations from 1 to 15 minutes.

The first step consists in the characterization of the thermally induced damage. The kinetics of decomposition were analyzed according to the duration of exposure and the nature of the matrix. Actually, thermoplastic matrices first melt with temperature and then decompose, whereas a thermosetting matrix decomposes directly. The decomposition of the matrix leads to the formation of cavities. Microscopic observations of the two faces (exposed and back) reveal the degree of matrix degradation (melt matrix, porosities, carbonaceous char layer). X-ray tomography enables to inspect the interply delamination and the porosity network.

In a second time, the residual flexural properties were examined. From the exposed plates, 10 specimens were extracted, corresponding to different degrees of degradation, in relation to their positions. The three-point bending tests were performed according to the European standard EN 2562 (8). The flexural properties were then characterized according to the duration of exposure, the position of the specimen in the plate and the nature of the matrix. The main purpose is to evaluate the criticality of flame exposure on interface damage state, which is a key factor ruling the load bearing capabilities of the materials.

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