
Modelling of the permanent strain of a titanium plate riveted to a composite plate under the exposure to a kerosene flame

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Abstract

Aircraft lightning has been carried out with a view to increase efficiency of fuel consumption. In that aim, light-weighted and efficient materials such as polymer matrix composite and titanium are used in aerospace designs (1). In particular, in the vicinity of aircraft engines, Interfaces for electrical and hydraulic routing are titanium plates assembled among composite structure. In this area, carbon-epoxy composites are a major challenge for safety requirements in terms of fire resistance (2). Hence the need to perform fire tests on components to meet safety regulations (3). Basically, carbon-epoxy titanium riveted plates assembly specimen (230x230 mm², carbon/epoxy laminates simply overlapped with titanium T40 plates, thickness=0.6mm) are exposed to a flame from an air/kerosene burner (cylindrical tube 50mm, flame at 1100 +/- 80 °C, heat flux of 116 kW/m²) (4), (5). Flame penetration through the sample or flame on the unexposed rear side before 15 minutes will cause the test to fail. The experimental set up, at laboratory scale, includes the temperature monitoring of both sides by means of IR cameras. The results show the importance of the thermo-mechanical response of the titanium plate (from both the thermal expansion and the fixed boundary conditions) and the assembly parameters (overlapping length and fastening pitch) on meeting the certification requirements. High thermal stresses (stemming from the flame exposure) on the titanium plate result in a thermally-induced buckling between rivets after a 30 seconds exposure. The V-shaped deformation of the Ti plate allows hot gases to pass through the assembly, ultimately leading to the ignition of pyrolysis gases on the back surface and the failure of the validation test.

These observations have raised the question of the physics involved in this phenomenon which, although explainable, was not expected to occur with that dramatic consequences. This has motivated the development of a numerical modelling with the first aim of identifying what mechanisms are necessary to explain the phenomenology and what are their respective effects on it. The second aim was to evaluate the ability of the modelling to quantitatively reproduce the phenomenon. To start, the modelling is based on a purposely simplified configuration: only the section of the titanium plate lying between the rivets is represented.

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It is supposed to be clamped at the rivets contact surfaces and it is subjected only to a thermal aggression reproducing the one measured experimentally. The constitutive behavior is supposed to be thermo-elasto-plastic, with a weak coupling between thermal transfers and mechanics. The geometry of the section is a slightly curved rectangle. This curvature is meant to promote the bending in the direction of the flame. Most of these choices made for the preliminary steps of the development (boundary conditions, 2D, mesh refinement, curved rectangle) are, in the process of evaluating the modeling, the subject of dedicated analyses.

The first step consists in characterizing the mechanical behavior of Ti plates as a function of temperature. Some parameters (coefficient of thermal expansion, Young modulus and yield strength) could be found in literature on limited temperature ranges (6). Thermo gravimetric and Differential Scanning Calorimetry analyses were carried out to investigate phase transitions with temperature (7). To determine the temperature-dependence of mechanical properties (Young's modulus, yield and ultimate strengths), tensile tests were performed up to 750°C by means of a testing machine equipped with a high-temperature oven. These tests are utmost important to determine the thermal and mechanical models' parameters.

The second step relies on the 2D simulation of the thermo-mechanical response of a Ti plate (through-the-thickness). Preliminary analyses show that the small strain assumption is not suitable to reproduce experimental results. A temperature ramp (from 0 to 840°C) is applied uniformly on one surface of the plate (flame-exposed surface) during 30s, followed by a 10s cooling down to room temperature (20°C). The back surface is subjected to natural convection at room temperature. The value of some parameters (convective heat transfer coefficient, strain hardening coefficient and initial curvature) was identified based on the model's sensitivity study. Convective heat transfer coefficient and initial curvature shows that their effects on the simulation results were negligible according to the final curvature.

Ultimately, three fastening pitches (25-35-45mm) were simulated. Maximum curvature after cooling have been compared to experimental measurements, showing very similar results for the 25mm pitch. Larger values of pitches did not correlate well with experimental measurements (~50% difference). This simple numerical model provides useful knowledge on the influence of geometrical parameters of the assembly on the Ti plate buckling during kerosene flame exposure. Thus, the plate's deflection may be minimized to prevent flame quenching. Further investigations are required to – (i) improve the representativity of the geometrical and numerical models by considering 3D representations of the assembly and temperature distribution – (ii) validate the model capabilities to estimate the out-of-plane displacement of the Ti plate.

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