Contribution ID: **368** Type: **Contributed Oral**

M4Or1B-02: Investigating the effect of cryogenic conditions on the elastic behaviour of fibre-reinforced polymer composite materials under tensile loading

Thursday 22 May 2025 09:45 (15 minutes)

As the aviation industry moves toward decarbonization, liquid hydrogen (LH2) emerges as a promising alternative fuel, offering the potential for zero carbon emissions during combustion. However, the successful use of LH2 in aircraft systems relies on understanding the structural integrity of composite materials under extreme temperature conditions as LH2 boils at 20 K (-253 °C). The tensile properties of polymer composite materials are essential to characterize and measuring them at cryogenic temperatures is therefore critical for assessing their viability in applications involving liquid hydrogen.

Several publicly available studies have indicated priority lists of materials and mechanical properties that need to be characterized under cryogenic conditions and within a liquid hydrogen environment to assess for compatibility with aerospace applications. For polymer composite materials, the top priority is carbon fibre-reinforced polymers (CFRP), followed by glass fibre-reinforced polymer (GFRP) materials. Both types of materials are typically selected for high-performance components in aircraft structures, due to their exceptional specific stiffness and strength properties. In addition, a range of auxiliary components will be essential for the adoption of LH2 as a fuel, however these are unlikely to pose such high requirements on properties but will still need thorough characterisation under cryogenic conditions. One such example is single-polymer composite (SPC) materials that, as the name implies, although consisting of a single material, still maintain the matrix and the reinforcement form that describes composites. These materials are becoming increasingly attractive to the energy industry, especially for piping applications, due to their low material cost and high-rate of production by means of tape-laying resulting in lower manufacturing costs. Their applicability to hydrogen-fuelled aircraft is also a possibility but will require comprehensive material characterisation at representative conditions to be undertaken.

In this work, tensile tests on three different fibre-reinforced polymer composite material systems (SPC, GFRP, CFRP) were carried out at room temperature, 77 K and 20 K by utilising a wet-bath cryostat to expose the specimens to a cryogenic environment. In the case of 77 K, simply submerging the test rig in liquid nitrogen is sufficient whereas for 20 K, a novel temperature control configuration was developed, operating on the principal of controllably boiling liquid helium inside the test dewar with a set of heating elements. The specimens were only loaded within their elastic region as the focus of this work was to highlight the effect of extreme low temperatures to their elastic response, namely Young's modulus and Poisson's ratio.

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Session Classification: M4Or1B - Hydrogen Technology and Compatible Materials