

TITLE: Investigation of Hydrogen Permeation and Microcrack Growth of Thermoplastic Composites through Cryogenic Cycling

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ABSTRACT:

Hydrogen fuel is a promising net-zero fuel alternative to current fossil fuels. Liquid hydrogen is favoured over gaseous hydrogen for because it has a higher volumetric energy density and can be stored at lower pressures (10 bar compared to 700 bar). Composite liquid hydrogen tanks are light weight and have a higher gravimetric efficiency compared to current metallic tanks, making them suitable for transport applications such as aerospace. The challenge with using composites for liquid hydrogen storage are hydrogen permeability and durability at cryogenic temperatures. Thermoset polymers are commonly used as a matrix for hydrogen tanks, but the free volume in the crosslinked network allows for hydrogen to permeate. Semi-crystalline polymers have shown to have better hydrogen barrier properties compared to amorphous thermoplastics and thermosets. The crystalline regions create torturous paths which decrease hydrogen permeation. The mismatch in the coefficient of thermal expansion between the fibres and the matrix create thermal stresses resulting in microcrack formation. After cryogenic cycling, the microcracks tend to grow, leading to increased hydrogen permeation/leakage, delamination and eventually tank failure.

This study investigated the hydrogen permeability and microcrack growth of carbon fibre/polyamide 11, carbon fibre/polyamide 11 with additives, and carbon fibre/polyamide 12 manufactured using automated fibre placement (AFP). For each material system, unidirectional and quasi-isotropic sample were manufactured. Samples were then subjected to cryogenic cycling between room temperature and 77 K for 10, 50, 100, and 200 cycles. The hydrogen permeability was measured after each cycle using a custom designed permeability cell based on the differential pressure method. A pressure differential of 10 bar to vacuum was used and the change in pressure in the high pressure and low-pressure chambers were evaluated, from which the permeability was calculated using Fick's law. However, with increasing microcrack density, transport was expected to transition from predominantly Fickian diffusion toward more Darcy-like flow through connected crack pathways. Overall, this study evaluated the effects of material system, laminate architecture (UD vs quasi-isotropic), and cryogenic cycling on hydrogen permeability, and related permeability changes to microcrack development and the potential transition from Fickian diffusion toward Darcy-type flow.

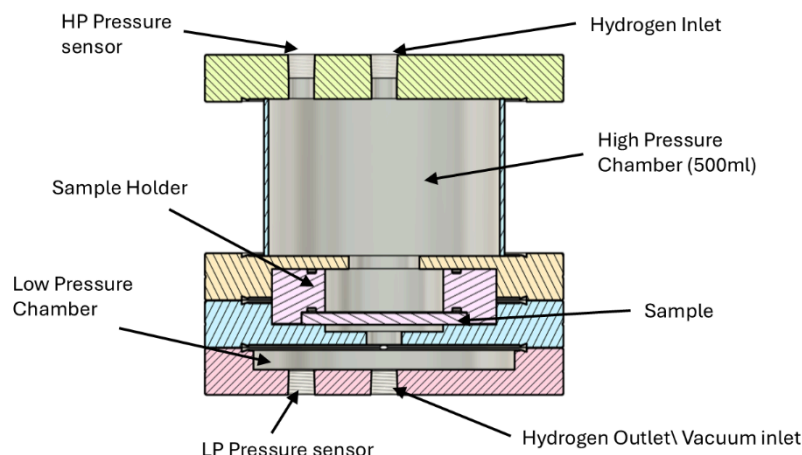


Figure 1: Custom designed hydrogen permeation chamber