



CASE STUDY

Ketan Pancholi
Robert Gordon
University
NCC (Part of HVM
Catapult)

The Challenge

A major challenge in clean transport and aerospace is storing enough energy onboard without making the storage system too heavy. Liquid hydrogen is attractive because it carries high energy and, in liquid form, occupies much less space than compressed gas. However, it must be stored at about -253°C , which creates a serious materials problem. While carbon fibre reinforced polymer (CFRP) tanks offer an attractive lightweight alternative to metal tanks, the polymer phase inside the composite can become brittle at cryogenic temperature. This can lead to the formation of microcracks, which then act as pathways for hydrogen leakage.

As a result, a material that appears strong and lightweight at room temperature may not remain safe, durable or leak-tight in liquid-hydrogen service. The challenge in this case study was therefore to identify whether a PAEK-based thermoplastic composite could be engineered to combine low hydrogen permeability, good manufacturability and resistance to cryogenic microcracking in a way that supports practical use in lightweight hydrogen storage systems.

Innovation

To address this challenge, the project developed and evaluated a PAEK-family polymer/PEEK composite system for cryogenic hydrogen-barrier applications. The aim was to improve the hydrogen barrier performance of CFRP thermoplastic structures while maintaining mechanical integrity and durability under cryogenic cycling. The work focused on blending a synthesised, compatible PAEK-based polymer with PEEK. The rationale was that the synthesised polymer would provide greater local chain mobility at low temperature and promote dispersion of amorphous regions within the crystalline phase. This offered a way to control crystal growth and crystallite development as temperature was reduced, which is important for limiting crack initiation.

The project therefore moved beyond polymer synthesis into controlled processing and morphology engineering. A practical blend-to-composite route was established, including polymer synthesis, confirmation of blendability with PEEK, melt blending, pelletising, hot pressing into films, composite lay-up with carbon fibre, and annealing. The thermal history and annealing conditions were deliberately tuned to control crystal size and crystallite structure, with the aim of improving resistance to cryogenic cracking while retaining low permeability. A 100 × 100 × 3 mm three-ply panel was manufactured and tested. Mechanical performance was assessed using short-beam bending and three-point bending, while cryogenic durability was evaluated through repeated liquid-nitrogen cycling. In this way, the project linked polymer chemistry, morphology control, processing and composite manufacture to the central challenge of developing a lightweight, leak-resistant cryogenic material system.

Result

A central challenge in liquid-hydrogen systems is that the materials needed to make tanks and components lightweight often become vulnerable in extreme cold. In this project, the aim was not simply to create a new polymer, but to find a practical way to stop the two main failure routes that hold back wider adoption: microcracking and leakage.

The project showed that a synthesised PAEK-based polymer could be blended successfully with PEEK without obvious phase separation and then processed into a carbon-fibre composite using a realistic manufacturing route. This was important because it meant the material was not confined to laboratory chemistry, but could be turned into films, laminates and representative composite panels.

The key advance came from what the project learned about morphology control. Rather than relying on chemistry alone, the work showed that blending the compatible polymer into PEEK helped disperse amorphous regions within the crystalline structure and gave the polymer chains more freedom to accommodate strain at low temperature. Processing and annealing were then used deliberately to control crystal growth and crystallite structure, reducing the likelihood of crack initiation while still maintaining a strong barrier to gas transport.

This translated into meaningful results. The composite delivered an interlaminar shear strength of 91.7 MPa, flexural strength of 1195 MPa, and flexural modulus of 80.2 GPa. At the same time, the developed CF-CryoPolymer showed permeability around 32 times lower than the cited CF-PEEK cryogenic benchmark. The project demonstrated a route to combining structural credibility, low leakage and cryogenic durability.

Impact

The significance of this work is that it offers a realistic path towards lighter, safer and longer-lasting cryogenic hydrogen components. If taken forward, the technology could reduce the dependence on heavier metal solutions, improve reliability in liquid-hydrogen service, and lower the risk of crack-assisted leakage in demanding applications. That matters across sectors where weight, durability and safety directly affect performance and cost, including long-haul transport, aerospace, maritime hydrogen systems, cryogenic valves, transfer lines, couplers and storage infrastructure. In practical terms, the project shows the potential for a new class of manufacturable cryogenic composites that could help move hydrogen systems from technically possible to commercially more viable. The project has undertaken commercial customer discovery and is seeking to move towards commercialisation.



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“NCC benefited from the academic expertise of Ketan, and was able to gather a database of key properties of PEEK and its modified version. The collaboration led to testing samples of modified PEEK version for enhanced cryogenic applications.”

Ketan Pancholi

“This project has created a credible route towards lighter, safer and longer-lasting cryogenic hydrogen components for transport decarbonisation. Working with NCC UK has been instrumental in providing access to facilities, industrial networks and translational expertise that have helped move the research beyond the laboratory and towards commercial relevance. The collaboration has strengthened the pathway from academic materials innovation to practical hydrogen applications.”