AEROSPACE TECHNOLOGY INSTITUTE

Hydrogen Capability Network

Hydrogen Innovation Initiative

HENRY ROYCE INSTITUTE

NPL

# UK Cryogenic & Hydrogen Materials Testing Landscape

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## Introduction

The Aerospace Technology Institute's (ATI) FlyZero project developed roadmaps covering the technologies needed for liquid hydrogen (LH2) flight to be viable[1]. These covered topics that are both generic (such as automation, digital twins and materials) and specific (such as aerodynamic modifications to manage dry wings, fuel cell development and gas turbine hydrogen combustion).

Building on FlyZero recommendations the ATI's Hydrogen Capability Network (HCN), through engagement with key stakeholders across academia and industry, has identified that the UK has strong existing knowledge and research capability in many of the topics required to deliver an aircraft capable of liquid-hydrogen-powered flight. There is, however, a clear exception with on-aircraft cryogenic hydrogen fuel storage and distribution systems.

The challenge relates specifically to the storage and distribution of hydrogen fuel between the fuel tank and propulsion source, across a wide range of fluid temperatures and pressures. A high-level overview of technologies and components used in a liquid hydrogen fuel system can be seen in Figure 1, as developed during an ATI Hub Innovation Showcase event[2].

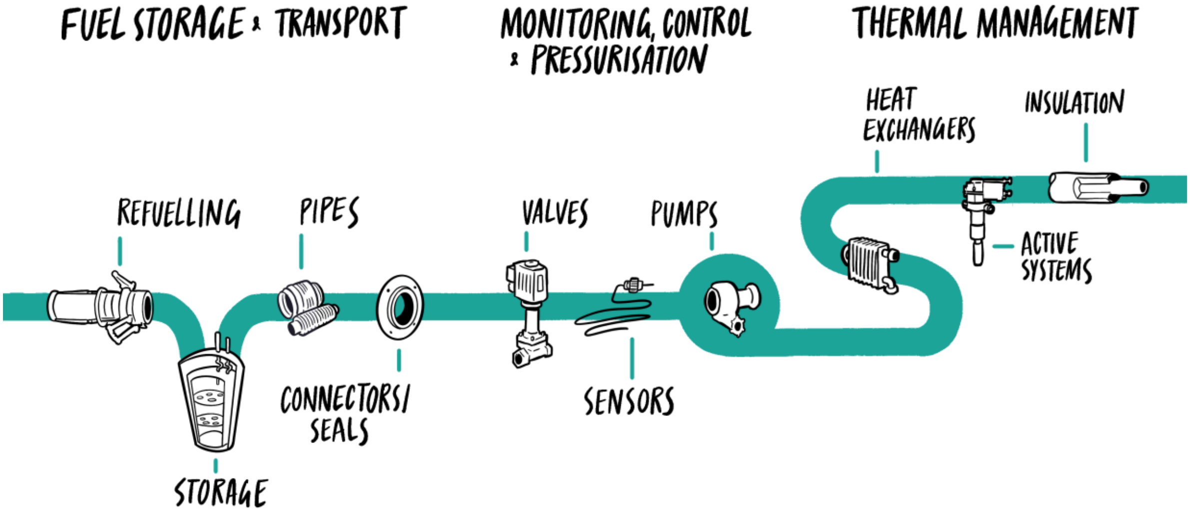

*Figure 1 : Schematic providing a high-level overview of technologies and components across a liquid hydrogen fuel system*

Supporting the ecosystem to accelerate the development of fundamental knowledge will enhance the UK's ability to contribute to the development of these technologies and therefore zero carbon aircraft. This aligns directly with both Government's Net Zero policy objectives and the objectives of the HCN. During the first 12 months of the HCN, the following underpinning research topics were identified as requiring particular focus to enable technology development:

- **Materials:** Fundamental material behaviour at cryogenic temperatures and hydrogen environments
- **Thermofluids:** Cryogenic hydrogen thermofluids behaviour
- **Health & Safety:** Cryogenic hydrogen health and safety protocols, modelling, and testing

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[1] FlyZero Reports Archive - Aerospace Technology Institute (ati.org.uk)
[2] ATI Hub – The ATI Hub is a space for innovators to connect, access expertise and collaborate.

The HCN is working to develop research proposals to address these topics, aligned to key research gaps and industrial priorities, as evaluated through international landscaping activities and workshops with industrial members.

To support researchers who would like to investigate the impact of hydrogen and cryogenic environments on materials, this report captures UK based, hydrogen and cryogenic materials testing capability. Specifically, this report highlights cryogenic test capability and only includes test capability with cryogenic (≤ 77 K) or hydrogen test environments. Test capability suited to the evaluation of metallics, polymers and composites are included, as evaluation of candidate materials across the LH2 fuel system currently includes austenitic stainless steels, aluminium based and nickel-based alloys, composite materials and sealant materials.

This report produced in collaboration between the HCN, the Hydrogen Innovation Initiative (HII), the National Physical Laboratory (NPL) and the Henry Royce Institute, serves an update to the report previously published by the Henry Royce Institute, "*Royce Hydrogen Blueprints*"[3]. This activity has partially been completed during the development of the Cryogenic Hydrogen Materials Testing Standards (CHYMES) programme, which is working to develop standardised material test methods for the tests discussed in this report.

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[3] UK-Hydrogen-Testing-Blueprint-1.2.pdf

# UK Cryogenic and Hydrogen Materials Testing Landscape Overview

This report summarises the cryogenic and hydrogen materials testing capabilities across UK - based commercial and research organisations. This covers test facilities for the evaluation of mechanical, thermal, hydrogen transport and other properties typically used to understand materials behaviour for design and certification purposes.

In order to highlight test capabilities that can further our fundamental understanding of materials behaviour in cryogenic and hydrogen environments, this document only considers facilities that can conduct testing either: in a cryogenic environment at 77 K or below, or in an environment of gaseous hydrogen, or using in-situ electrochemical charging.

This report should therefore not be used as an exhaustive list of all capabilities at these organisations but may be used to understand capabilities under these test conditions.

The following UK based organisations have materials testing capability that meet these criteria:

1. University of Bath
2. University of Birmingham
3. University of Bristol
4. Composite Test & Evaluation Ltd
5. Cranfield University
6. Darvick
7. Element Materials Technology
8. Hive Composites
9. University of Manchester
10. National Composites Centre
11. National Physical Laboratory
12. University of Oxford
13. University of Southampton
14. Science and Technology Facilities Council
15. University of Strathclyde
16. UK Atomic Energy Authority
17. The Welding Institute
18. Warwick Manufacturing Group

All capabilities captured are open access and are believed to be correct at the time of publishing. Test capability was submitted to the HCN by the individual organisations listed using a standardised data template. Planned future capabilities are not included for clarity. A Point of Contact (POC) for technical enquiries from each organisation is also listed.

The following observations may be made about the current state of play of UK cryogenic and hydrogen materials testing capability, with the findings illustrated in Figure 2:

- **Mechanical Testing:** There is extremely limited capacity for mechanical testing of materials in cryogenic hydrogen test environments, with just a single capability being commissioned at Cranfield University. Cryogenic mechanical behaviour of materials below 77 K may be evaluated at few sites of limited capacity.
- **Transport Testing:** Hydrogen transport within materials is evaluated at multiple locations and there has been work to benchmark these, including under liquid hydrogen conditions.
- **Thermal Testing:** Inert-atmosphere, cryogenic thermophysical property testing is available at multiple sites, however there is no capability to conduct testing in a hydrogen environment.
- **Other Testing:** There are a very limited number of micro/nano-scale test capabilities for non-destructive evaluation in cryogenic or hydrogen environments and limited specialised testing for the evaluation of tribology or other phenomena related effects.

# UK Cryogenic and Hydrogen Materials Testing Landscape

**The following UK organisations have the capability to test materials under the following environment conditions:**

**Cryogenic hydrogen** ◉ ≤20 K ● ≤77 K

**Cryogenic inert** ◉ ≤20 K ● ≤77 K

**In-situ hydrogen** ●

*Not available* ○

1. University of Bath
2. University of Birmingham
3. University of Bristol
4. Composite Test & Evaluation Ltd
5. Cranfield University
6. Darvick
7. Element Materials Technology
8. Hive Composites
9. University of Manchester
10. National Composites Centre
11. National Physical Laboratory
12. University of Oxford
13. University of Southampton
14. Science and Technology Facilities Council
15. University of Strathclyde
16. UK Atomic Energy Authority
17. The Welding Institute
18. Warwick Manufacturing Group

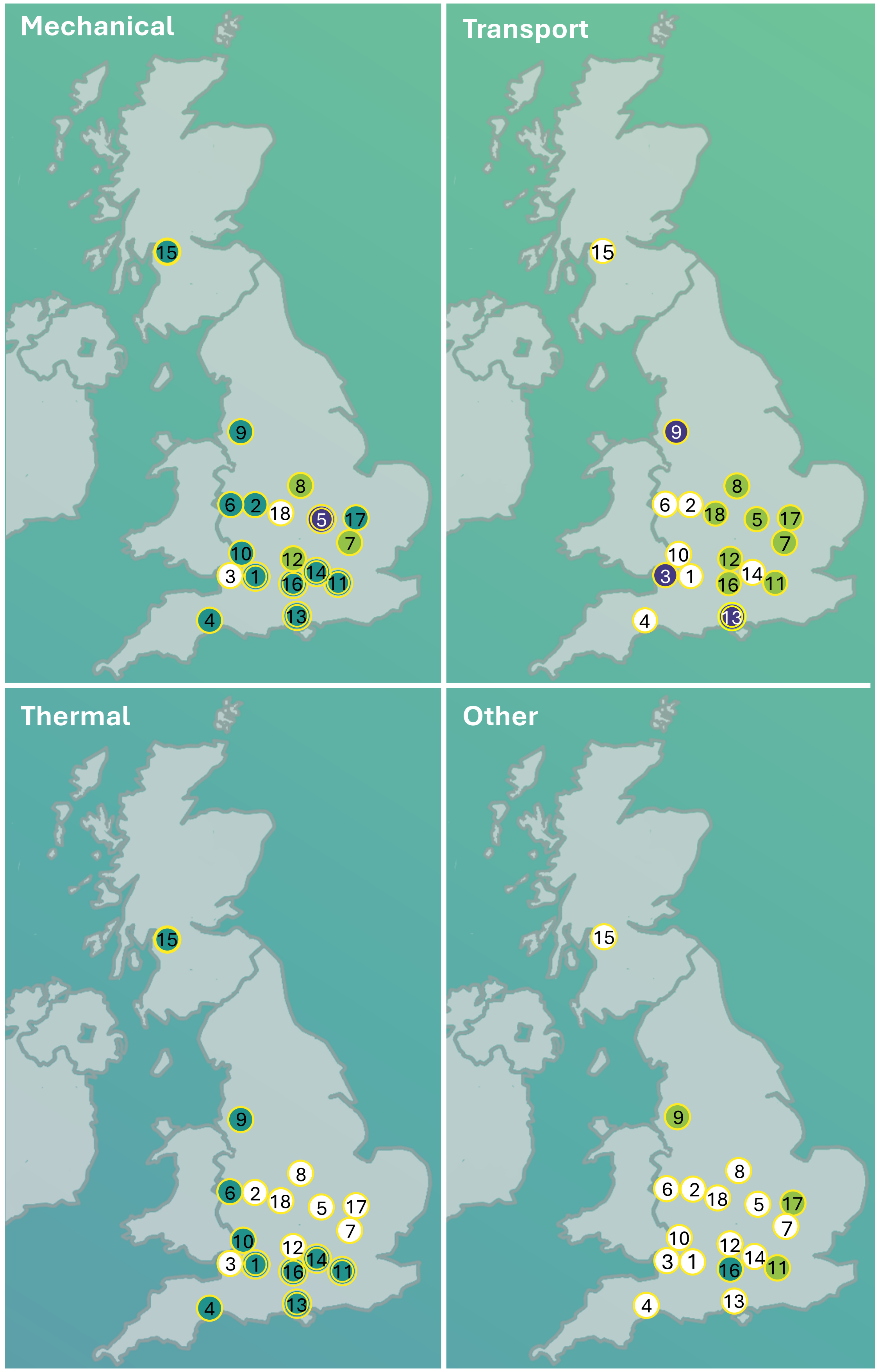

*Figure 2: UK Cryogenic and Hydrogen Materials Testing Landscape*

## Conclusion

Knowledge of fundamental materials behaviour in cryogenic hydrogen environments is a key enabler for the development of liquid hydrogen technologies. This fundamental understanding is required early in the development phase of liquid hydrogen powered aircraft, with demand for material test capability expected to grow. The UK's capability to test materials in cryogenic and hydrogen environments is currently found in a small number of organisations, primarily in academic institutions, where capacity to conduct test programmes is limited. The variety of testing available is not universal across these organisations. An expansion of test capability will be required to not only address missing capability with respect to testing environments, but also to provide UK based capacity for future material evaluation programmes.

However, capability is evolving rapidly, with many organisations developing more capability than currently listed across the variety of tests. This momentum is being supported by a number of on-going programmes, including the work at the ATI to develop standardised materials test methods (CHYMES[4]), and wider infrastructure development for the supply of liquid hydrogen in quantities suitable for research.

The Henry Royce Institute recently published recommendations under the National Materials Innovation Strategy[5]. The strategy focuses effort on the largest opportunities for impact. One of six theme areas, Energy Solutions highlighted the opportunities in materials for hydrogen storage, transport and end use, calling for research and development programmes to focus on the UK's essential needs for energy, transport, aerospace, cryogenics and more specific defence requirements.

The Henry Royce Institute is also supporting investment in cryogenic test capability. Under the theme of Materials for Demanding Environments, Cranfield University was awarded a grant for a fatigue rig for cryogenic, high-pressure hydrogen testing, and the capability is currently in development.

NPL has been working in the clean hydrogen sector for over two decades and as of 2024 has approximately 30 experts from across multiple scientific disciplines working to develop the necessary measurement techniques, protocols, modelling tools and standards. Over that period, NPL's work in hydrogen has focused on supporting the development of fuel cells and electrolysers, providing reliable gas quality measurements, assessing the suitability of existing gas infrastructure, and developing new test capabilities to support deployment of hydrogen transportation and storage infrastructure. In response to identified measurement challenges as highlighted in the *Energy transition: Measurement needs within the hydrogen industry* report[6], NPL has invested in developing capability for measuring the performance of advanced materials at cryogenic hydrogen temperatures to better support the development of emerging liquid hydrogen applications.

The Hydrogen Innovation Initiative (HII) also aims to continue its support of cross-sector collaboration and knowledge sharing for materials research and support the development of critical infrastructure to enable the hydrogen economy in its next phase operation.

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[4] https://www.ati.org.uk/wp-content/uploads/2023/11/Materials-Standards-Intervention-Final-Slides.pdf

[5] https://www.royce.ac.uk/collaborate/innovationstrategy/

[6] https://www.npl.co.uk/resources/energy-transition/hydrogen-report-2024

# Appendix – Detailed Capability per Organisation

## 1. University of Bath

| University of Bath | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Dr Andrew Rhead;<br>atr21@bath.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Cryostat | Vacuum | Y | 20 | 300 | 1 | | 300 | | | Vacuum based cryostat on Instron 8803 hydraulic fatigue system. Optical access. 100 kN and 650 kN (static)/500 kN (fatigue) load cells. Cryostat currently designed for 300 kN. |
| | Slow strain rate | Y | Y | Y | Cryostat | Vacuum | Y | 20 | 300 | 1 | | 300 | | | |
| | Low cycle fatigue | Y | Y | Y | Cryostat | Vacuum | Y | 20 | 300 | 1 | | 300 | | | |
| | Fracture toughness | Y | Y | Y | Cryostat | Vacuum | | 20 | 300 | 1 | | 300 | | | |
| | Impact | Y | Y | Y | Cryostat | Helium | | 20 | 300 | 1 | | Energy (J) | | 50 | Split Hopkinson Pressure Bar with gaseous helium and cold head based cooling. Plans for cryostat conversion from mechanical test to drop weight. |
| | Interlaminar shear | | Y | | Cryostat | Vacuum | | 20 | 300 | 1 | | | | | |

| University of Bath | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Dr Andrew Rhead;<br>atr21@bath.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Thermal | Thermal conductivity | Y | Y | Y | | *Metallic* | | 20 | 300 | | | | | | |
| | | | | | | *Non-metallic* | | 20 | 300 | | | | | | |
| | Thermal cycling | Y | Y | Y | Cryostat | Vacuum | | 20 | 300 | 1 | | | | | |
| | Thermal shock | Y | Y | Y | Cryostat | Vacuum | | 20 | 300 | 1 | | | | | |

## 2. University of Birmingham

| University of Birmingham | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | https://www.birmingham.ac.uk/research/energy/research/centre-energy-storage | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | Prof. Yulong Ding;<br>y.ding@bham.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | N | None | Air | N | 50 | 700 | | | 100 | | | |

## 3. University of Bristol

| University of Bristol | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Dr. Lui Skytree; lt7006@bristol.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | Y | Y | Y | Wet bath or gas change | Hydrogen | | 77 | 323 | 80 | | | | | Use the accumulation method to determine permeability (pressure sensor based). CHyPr I - Holds 25-30mm disc or square samples. Future ambitions: CHyPr 2, samples will be ~100mm disc and pressure up to 100 bar, and CHyPr 3, complete with a cryostat system capable of full temperature control from 20 to 300 K. |

## 4. Composite Test & Evaluation

| Composite Test & Evaluation | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | www.compositetest.com | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | contact@compositetest.com | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Wet bath or gas change | Air | | 77 | 473 | 77 | | 250 | | | Using pre-immersion in LN2 |
| | Slow strain rate | Y | Y | Y | Wet bath or gas change | Air | | 77 | 473 | 77 | | 250 | | | |
| | Low cycle fatigue | Y | Y | Y | None | Air | | 300 | 300 | 300 | | 250 | | | |
| | High cycle fatigue | Y | Y | Y | None | Air | | 300 | 300 | 300 | | 250 | | | |
| | Fracture toughness | Y | Y | Y | Wet bath or gas change | Air | | 77 | 473 | 77 | | 250 | | | Using pre-immersion in LN2 |
| | Interlaminar shear | | Y | | Wet bath or gas change | Air | | 77 | 473 | 77 | | 250 | | | |
| Thermal | Thermal shock | Y | Y | Y | Wet bath or gas change | | | 77 | 573 | | | | | | Switching between LN2 immersion and Hot Oven with manual transfer |

## 5. Cranfield University

| Cranfield University | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.cranfield.ac.uk/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Dr. Francesco Fanicchia; francesco.fanicchia@cranfield.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Wet bath or gas change | Hydrogen | Y | 20 | 1200 | 1 | | 100 | | | LH2 rig 100kN, other rigs 50kN. LH2 20-300K. GH2(1bar) 300-1200K. Pre-charged hydrogen 77-1200K. Polymer limited on stroke (100mm full scale). (Max frequency dependent on stroke requirement) |
| | Slow strain rate | Y | Y | Y | Wet bath or gas change | Hydrogen | Y | 20 | 1200 | 1 | | 100 | | | |
| | Low cycle fatigue | Y | Y | Y | Wet bath or gas change | Hydrogen | Y | 20 | 1200 | 1 | | 100 | 100 | | |
| | High cycle fatigue | Y | Y | Y | Wet bath or gas change | Hydrogen | Y | 20 | 1200 | 1 | | 100 | 100 | | |
| | Fracture toughness | Y | N | N | Wet bath or gas change | Hydrogen | | 20 | 1200 | 1 | | 100 | | | PD crack growth requires conducting specimens. LH2 20-300K. GH2(1bar) 300-1200K. Pre-charged hydrogen 77-1200K. Polymer limited on stroke (100mm full scale). LH2 rig 100kN, other rigs 50kN |

| Cranfield University | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.cranfield.ac.uk/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Dr. Francesco Fanicchia; francesco.fanicchia@cranfield.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 1100 | 150 | | | | | |
| Thermal | Thermal cycling | Y | Y | Y | Wet bath or gas change | H2O, O2, N2, Ar, etc. | | 300 | 1500 | 1 | 10 | | | | Several thermal cycling rigs working in different, controllable, atmospheres. Cooling rates up to 1000°C/min by direct water jet spray. |
| | Thermal shock | Y | Y | Y | Wet bath or gas change | H2O, O2, N2, Ar, etc. | | 300 | 1500 | 1 | 10 | | | | |

## 6. Darvick

| Darvick | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | www.darvick.co.uk | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Vicki Wilkes; vicki@darvick.co.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Pressure vessel | Hydrogen | Y | 300 | 300 | 300 | | | | | UKAS accredited up to 1000$^{o}$C, can heat up to 2000$^{o}$C |
| | Slow strain rate | Y | Y | Y | Pressure vessel | Hydrogen | Y | 300 | 300 | 300 | | | | | Lowest strain rate 5 x 10$^{-6}$ |
| | High cycle fatigue | Y | Y | Y | Pressure vessel | Hydrogen | Y | 300 | 300 | 300 | | | | 0.0001 | |
| | Fracture toughness | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 300 | 300 | | | | | |
| Thermal | Thermal cycling | Y | Y | Y | Pressure vessel | Hydrogen | | 77 | 1000 | 100 | 100 | | | | Can go through 0$^{o}$C on a thermal cycle |

## 7. Element Materials Technology (UK)

| Element Materials Technology (UK) | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | www.element.com | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | glyn.morgan@element.com | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | | | Pressure vessel | Hydrogen | | 300 | 300 | 300 | | 100 | | | |
| | Slow strain rate | Y | | | Pressure vessel | Hydrogen | | 300 | 300 | 300 | | 100 | | | ASTM G142. Also available in-situ electrochemical charging to AMPP/Nace TM0198 |
| | High cycle fatigue | Y | | | Pressure vessel | Hydrogen | | 300 | 300 | 300 | | 100 | | 0.0001 | In-situ electrochemical charging also available |
| | Fracture toughness | Y | | | Pressure vessel | Hydrogen | | 300 | 300 | 300 | | 100 | | | ASTM E1820 / EPRG Guidelines. In-situ electrochemical charging available |
| Transport | Permeation, diffusivity | | Y | | Pressure vessel | | | 240 | 480 | 300 | | | | | |

## 8. Hive Composites

| Hive Composites | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | www.hivecomposites.com | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | p.hansen@hivecomposites.com | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | N | Y | Y | Pressure vessel | Hydrogen | Y | 300 | 360 | 100 | | 150 | | | Offline exposure in H2 pressure vessels, subsequent testing on Zwick 150kN test machine with test cabinet up to 200C. Offline exposure cabinet down to -85$^{0}$C. Can also perform H2 RGD tests. |
| | Slow strain rate | N | Y | Y | Pressure vessel | Hydrogen | | 300 | 360 | 100 | | 150 | | | |
| | Low cycle fatigue | N | Y | Y | Pressure vessel | Hydrogen | Y | 300 | 360 | 100 | | 150 | | | |
| | Impact | N | Y | Y | Pressure vessel | Hydrogen | | 300 | 360 | 100 | | Energy (J) | | 100 | Offline exposure in H2 pressure vessels, subsequent testing on Charpy or drop-weight impact frame |
| | Interlaminar shear | | Y | | Pressure vessel | Hydrogen | | 300 | 360 | 100 | | 150 | | | |
| Transport | Permeation, diffusivity | | Y | Y | Pressure vessel | Hydrogen | | 300 | 360 | 100 | | | | | |

## 9. University of Manchester

| University of Manchester | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | royce@manchester.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Immersion | LN2 | N | 77 | 300 | 1 | | 100 | | | |
| | Slow strain rate | Y | Y | Y | Immersion | LN2 | N | 77 | 300 | 1 | | 100 | | | Also available at up to 300 bar from room temperature to 300°C |
| | Low cycle fatigue | Y | Y | Y | Immersion | LN2 | N | 77 | 300 | 1 | | 100 | 20 | 0.1 | |
| | High cycle fatigue | Y | Y | Y | | Ar | N | 300 | 1300 | 1 | | 100 | 20 | 1 | |
| | Fracture toughness | Y | Y | Y | Immersion | LN2 | | 77 | 300 | 1 | | 100 | | | Also available at up to 300 bar from room temperature to 300°C |
| | Impact | Y | Y | Y | Pre-immersion | LN2 | | 77 | 300 | 1 | | | | | |

| University of Manchester | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | royce@manchester.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 300 | 100 | | | | | |
| | *Thermal desorption spectroscopy* | Y | Y | Y | Cryostat | Hydrogen | | 200 | 1273 | 1 | | | | | |
| Thermal | Specific heat capacity | Y | Y | Y | | *Metallic* | | 300 | 1300 | | | | | | |
| | | | | | | *Non-metallic* | | 300 | 1300 | | | | | | |
| | Thermal expansion | Y | N | N | | *Metallic* | | 100 | 1300 | | | | | | |
| | | | | | | *Non-metallic* | | | | | | | | | |
| | Thermal cycling | Y | Y | Y | | | | 77 | 453 | 1 | 10 | | | | |
| Other | Mechanical testing with in-situ imaging | Y | Y | Y | | Vacuum | | 100 | 1073 | 1 | | | | | |

## 10. National Composites Centre

| National Composites Centre | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | https://www.nccuk.com/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | hydrogen@nccuk.com | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | N | Y | Y | Wet bath or gas change | Air | N | 77 | 330 | 1 | | | | | The NCC's 3D printed cryo chambers are used with cryogenic nitrogen gas dispensers to chill the specimens |
| | Low cycle fatigue | N | Y | Y | Wet bath or gas change | Air | N | 77 | 330 | 1 | | | | | |
| | High cycle fatigue | N | Y | Y | Wet bath or gas change | Air | N | 77 | 330 | 1 | | | | | |
| | Interlaminar shear | | Y | | Wet bath or gas change | Air | | | | | | | | | |
| Thermal | Thermal cycling | N | Y | Y | Wet bath or gas change | Liquid Nitrogen | | 77 | 330 | 1 | | | | | |
| | Thermal shock | N | Y | Y | Wet bath or gas change | Liquid Nitrogen | | 77 | 330 | 1 | | | | | |

## 11. National Physical Laboratory

| NPL | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | https://www.npl.co.uk | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | stefanos.giannis@npl.co.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Cryostat | Helium | N | 20 | 300 | 1 | | 100 | | | |
| | Slow strain rate | Y | Y | Y | Pressure vessel | Hydrogen | N | 277 | 473 | 200 | | 50 | | | Min strain rate is $10^{-7}$ $s^{-1}$ |
| | Low cycle fatigue | Y | Y | Y | Cryostat | Helium | N | 20 | 300 | 1 | | 100 | 20 | 0.1 | |
| | High cycle fatigue | Y | Y | Y | Cryostat | Helium | N | 20 | 300 | 1 | | 100 | 20 | 1 | |
| | Fracture toughness | Y | Y | Y | Cryostat | Helium | | 20 | 300 | 1 | | 100 | | | |
| | Micro-, Nano-mechanical testing | Y | Y | Y | | Vacuum | | 77 | 1073 | 1 | | 0.0005 | | | |
| | Interlaminar shear | | Y | | Cryostat | Helium | | 20 | 300 | 1 | | 100 | | | |

| NPL | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.npl.co.uk | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | stefanos.giannis@npl.co.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 300 | 100 | | | | | |
| | Thermal desorption spectroscopy | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 1173 | 200 | | | | | |
| Thermal | Thermal conductivity | Y | Y | Y | | *Metallic* | | 4 | 1670 | | | | | | |
| | | | | | | *Non-metallic* | | 153 | 1670 | | | | | | |
| | Thermal Diffusivity | Y | Y | Y | | *Metallic* | | 4 | 1848 | | | | | | |
| | | | | | | *Non-metallic* | | 153 | 1848 | | | | | | |
| | Specific heat capacity | Y | Y | Y | | *Metallic* | | 4 | 1773 | | | | | | |
| | | | | | | *Non-metallic* | | 93 | 1773 | | | | | | |
| | Thermal expansion | Y | Y | Y | | *Metallic* | | 4 | 1773 | | | | | | |
| | | | | | | *Non-metallic* | | 123 | 1773 | | | | | | |
| | Thermal cycling | Y | Y | Y | Wet bath or gas change | Helium | | 77 | 453 | 1 | 10 | | | | |
| | Thermal shock | Y | Y | Y | Wet bath or gas change | Helium | | 203 | 573 | 1 | 40 | | | | |

| NPL | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.npl.co.uk | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | stefanos.giannis@npl.co.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Other | Static charging | Y | Y | Y | Pressure vessel | Hydrogen | N | 277 | 473 | 200 | | | | | |

## 12. University of Oxford

| University of Oxford | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | [https://mechmat.web.ox.ac.uk/](https://mechmat.web.ox.ac.uk/) | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K $min^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | emilio.martinez-paneda@eng.ox.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Wet bath or gas change | In-situ Electro-chemical | Y | 300 | 300 | 1 | | 75 | | | |
| | Slow strain rate | Y | Y | Y | Wet bath or gas change | In-situ Electro-chemical | Y | 300 | 300 | 1 | | 75 | | | |
| | Low cycle fatigue | Y | Y | Y | Wet bath or gas change | In-situ Electro-chemical | Y | 300 | 300 | 1 | | 75 | | | |
| | High cycle fatigue | Y | Y | Y | Wet bath or gas change | In-situ Electro-chemical | Y | 300 | 300 | 1 | | 75 | | | |
| | Fracture toughness | Y | Y | Y | Wet bath or gas change | In-situ Electro-chemical | | 300 | 300 | 1 | | 75 | | | |

| University of Oxford | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://mechmat.web.ox.ac.uk/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | emilio.martinez-paneda@eng.ox.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | Y | Y | Y | Wet bath or gas change | Hydrogen | | 300 | 520 | 15 | | | | | |
| | Thermal desorption spectroscopy | Y | Y | Y | | | | 300 | 1273 | | | | | | |

## 13. University of Southampton

| University of Southampton | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.southampton.ac.uk/engineering/research/groups/energy_technology/institute_of_cryogenics.page | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Dr Wendell Bailey ; wosb@soton.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Cryostat | Helium | N | 20 | 300 | 1 | | 50 | | | |
| | Slow strain rate | Y | Y | Y | Cryostat | Helium | N | 20 | 300 | 1 | | 50 | | | Lower limit of strain rate is from 8.33 x 10$^{-8}$s$^{-1}$ to 3 x 10$^{-7}$ s$^{-1}$ for composites, polymers and metallic samples (depends on their length) |
| | Low cycle fatigue | Y | Y | Y | Cryostat | Nitrogen | Y | 110 | 300 | 1 | | 300 | | | |
| | Fracture toughness | Y | Y | Y | Cryostat | Helium | | 20 | 300 | 1 | | 50 | | | |
| | Impact | Y | Y | Y | Cryostat | Nitrogen/ Helium | | 50 | 373 | 1 | | Energy (J) | | 200 | |
| | Interlaminar shear | | Y | | Cryostat | Helium | | 20 | 300 | 1 | | 50 | | | |

| **University of Southampton** | | **Material Type** | | | **Environment hardware** | | | **Environmental parameters** | | | | **Mechanical parameters** | | | **Brief description of equipment** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | https://www.southampton.ac.uk/engineering/research/groups/energy_technology/institute_of_cryogenics.page | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate ($\text{K min}^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | Dr Wendell Bailey ; wosb@soton.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transpor | Permeation, diffusivity | Y | Y | Y | Pressure vessel | Hydrogen/ Helium | | 20 | 300 | 2 | | | | | |
| Thermal | Thermal conductivity | Y | Y | Y | | *Metallic*<br>*Non-metallic* | | 4<br>4 | 300<br>300 | | | | | | PPMS in Helium |
| | Thermal Diffusivity | Y | Y | Y | | *Metallic*<br>*Non-metallic* | | 4<br>4 | 300<br>300 | | | | | | |
| | Specific heat capacity | Y | Y | Y | | *Metallic*<br>*Non-metallic* | | 4<br>4 | 300<br>300 | | | | | | |
| | Thermal expansion | Y | Y | Y | | *Metallic*<br>*Non-metallic* | | 4<br>4 | 373<br>373 | | | | | | Dilatometer |
| | Thermal cycling | Y | Y | Y | | | | 20 | 373 | 1 | 2 | | | | |
| | Thermal shock | Y | Y | Y | | | | 77 | 373 | 1 | 40 | | | | |
| Oth | Tribology & Wear | Y | Y | Y | Cryostat | Nitrogen | | 110 | 373 | 1 | | | | | |

## 14. Science and Technology Facilities Council

| STFC | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.isis.stfc.ac.uk/Pages/engin-x.aspx | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | ISIS: tung-lik.lee@stfc.ac.uk;<br>TD: graham.appleby@stfc.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | N | Cryostat | Vacuum | N | 7 | 500 | 1 | | 100 | | | Available at ISIS |
| | Slow strain rate | Y | Y | N | Cryostat | Vacuum | N | 4 | 500 | 1 | | 100 | | | Available at ISIS (down to 7K) & Technology Department (down to 4K) |
| | Low cycle fatigue | Y | Y | N | Cryostat | Vacuum | N | 7 | 500 | 1 | | 100 | 0 | 20 | Available at ISIS (down to 7K) & Technology Department (down to 77K) |
| | High cycle fatigue | Y | Y | N | Cryostat | Vacuum | N | 7 | 500 | 1 | | 100 | 0 | 20 | Available at ISIS (down to 7K) & Technology Department (down to 77K) |
| | Fracture toughness | Y | Y | N | Cryostat | Vacuum | | 7 | 500 | 1 | | 100 | | | Available at ISIS |

| STFC | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.isis.stfc.ac.uk/Pages/engin-x.aspx | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | ISIS: tung-lik.lee@stfc.ac.uk; TD: graham.appleby@stfc.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Thermal | Thermal expansion | Y | Y | N | | *Metallic* | | 4 | 500 | | | | | | Available at ISIS (down to 7K) & Technology Department (down to 4K) |
| | | | | | | *Non-metallic* | | 4 | 500 | | | | | | |
| | Thermal cycling | Y | Y | N | Cryostat | Vacuum | | 7 | 500 | 1 | | | | | Available at ISIS - Maximum cooling ramp rate is 0.03 K s$^{-1}$. Maximum heating ramp rate is 9 K s$^{-1}$ |
| | Thermal shock | N | N | N | Wet bath or gas change | Nitrogen | | 77 | | | | | | | Available at the Technology Department facility |

## 15. University of Strathclyde

| University of Strathclyde | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | Advanced Materials Research Laboratory; https://cryogenicpropulsion.com/our-team/professor-min-zhang/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{-1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | fiona.sillars@strath.ac.uk; min.zhang@strath.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | N | N | Wet bath or gas change | In-situ Electro-chemical | N | 280 | 300 | 1 | | 100 | | | Instron 8801 with in-house developed electrochemical charging set-up, therefore only conductive materials possible |
| | Low cycle fatigue | Y | N | N | Wet bath or gas change | In-situ Electro-chemical | N | 280 | 300 | 1 | | | 15 | 1 | |
| | High cycle fatigue | Y | N | N | Wet bath or gas change | In-situ Electro-chemical | N | 280 | 300 | 1 | | | 15 | 1 | |
| | Fracture toughness | Y | N | N | Wet bath or gas change | In-situ Electro-chemical | | 280 | 300 | 1 | | | | | |
| | Impact | Y | Y | Y | Wet bath or gas change | Air | | 77 | 333 | 1 | | | | | |
| Transport | Permeation, diffusivity | Y | N | N | Wet bath or gas change | Hydrogen | | | | | | | | | |

| University of Strathclyde | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | [Advanced Materials Research Laboratory;](https://cryogenicpropulsion.com/our-team/professor-min-zhang/) [https://cryogenicpropulsion.com/our-team/professor-min-zhang/](https://cryogenicpropulsion.com/our-team/professor-min-zhang/) | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | fiona.sillars@strath.ac.uk; min.zhang@strath.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Thermal | Thermal shock | Y | Y | Y | Wet bath or gas change | Nitrogen | | 77 | | | | | | | |

## 16. UK Atomic Energy Authority

| UK Atomic Energy Authority | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://ccfe.ukaea.uk/divisions/fusion-technology/applied-materials-technology/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Glyn.Stanton@ukaea.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Cryostat | Helium | Y | 20 | 1273 | 1 | | 100 | | | |
| | Slow strain rate | Y | Y | Y | Cryostat | Helium | Y | 20 | 1273 | 1 | | 100 | | | |
| | Low cycle fatigue | Y | Y | Y | Cryostat | Helium | Y | 20 | 1273 | 1 | | 100 | 20 | 0.1 | |
| | High cycle fatigue | Y | Y | Y | Cryostat | Helium | | 20 | 30 | 1 | | 100 | 20 | 1 | |
| | Fracture toughness | Y | Y | Y | Cryostat | Helium | | 20 | 1273 | 1 | | 100 | | | |
| | Micro-, Nano-mechanical testing | Y | Y | Y | Vacuum | | | 77 | 300 | 1 | | 0.0005 | | | |
| | Interlaminar shear | | Y | | Cryostat | Helium | | 20 | 300 | 1 | | 100 | | | |

| UK Atomic Energy Authority | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://ccfe.ukaea.uk/divisions/fusion-technology/applied-materials-technology/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Glyn.Stanton@ukaea.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 300 | 100 | | | | | |
| Thermal | Thermal conductivity | Y | Y | Y | | *Metallic* | | 4 | 1670 | | | | | | UKAEA PPMS can perform measurements of sample thermal conductivity, resistivity, Seebeck coefficient and thermoelectric figure of merit |
| | | | | | | *Non-metallic* | | 153 | 1670 | | | | | | |
| | Thermal Diffusivity | Y | Y | Y | | *Metallic* | | 4 | 1848 | | | | | | UKAEA MRF - Diffusivity can be calculated from thermal conductivity, density and specific heat capacity |
| | | | | | | *Non-metallic* | | 153 | 1848 | | | | | | |
| | Specific heat capacity | Y | Y | Y | | *Metallic* | | 4 | 1773 | | | | | | UKAEA MRF - UKAEA PPMS measure the specific heat capacity of samples of mass 1 – 200 mg |
| | | | | | | *Non-metallic* | | 93 | 1773 | | | | | | |
| | Thermal expansion | Y | Y | Y | | *Metallic* | | 4 | 1773 | | | | | | Dilatometer |
| | | | | | | *Non-metallic* | | 123 | 1773 | | | | | | |

| UK Atomic Energy Authority | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://ccfe.ukaea.uk/divisions/fusion-technology/applied-materials-technology/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | Glyn.Stanton@ukaea.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| | Thermal cycling | Y | Y | Y | Wet bath or gas change | | | 77 | 453 | 1 | 10 | | | | |
| | Thermal shock | Y | Y | Y | | | | 203 | 573 | 1 | 40 | | | | |
| Other | Nano-Indentation | Y | Y | Y | | Vacuum | | 123 | 1279 | | | | | | UKAEA MRF – In-situ nano indenter with cryo (-150C) and high temperature (1000C) modules as well as ambient temperature rotation and tilt stage. Radioactive sample compatible (limits apply) |
| | Ga FIB-SEM | Y | Y | Y | | Vacuum | | 123 | 300 | | | | | | UKAEA MRF - Ga FIB with cryo stage (-150C) for low temperature FIB operation. Radioactive sample compatible (limits apply) |

## 17. The Welding Institute

| TWI | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.twi-global.com/contact | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | michael.dodge@twi.co.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Mechanical | Quasi-static tension | Y | Y | Y | Pressure vessel | Hydrogen | N | 290 | 353 | 450 | | 100 | | | Various servo-hydraulic load frames and pressure vessels. Can be upgraded to 200kN. When testing at 150 Bar we can do -40'C at a max of 25kN |
| | Slow strain rate | Y | Y | Y | Pressure vessel | Hydrogen | N | 290 | 353 | 450 | | 100 | | | Can be upgraded to 200kN. Strain rate depends on specimen size. Lower rate circa 10-7/s typical |
| | High cycle fatigue | Y | Y | Y | Pressure vessel | Hydrogen | N | 290 | 353 | 450 | | 100 | 3 | 0.0001 | Various servo-hydraulic load frames and pressure vessels. |
| | Fracture toughness | Y | Y | Y | Pressure vessel | Hydrogen | | 290 | 353 | 450 | | 100 | | | Various servo-hydraulic load frames and pressure vessels. Can be upgraded to 200kN |

| TWI | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Link | https://www.twi-global.com/contact | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| POC | michael.dodge@twi.co.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| | Impact | Y | Y | Y | | Air | | 77 | 573 | 1 | | Energy (J) | | | Sheen drop-weight impact tester, Pellini, Charpy |
| Transport | Permeation, diffusivity | Y | Y | Y | Pressure vessel | Hydrogen | | 295 | 423 | 250 | | | | | High pressure permeation cell, capable of testing with various gases. Electrochemical permeation (D-S cell) also available at ambient pressure. |
| | Thermal desorption spectroscopy | Y | N | N | | | | 300 | 1373 | 1 | | | | | Bruker Galileo G8 with Mass Spectrometer, post hydrogen charging |
| Other | Static charging | Y | Y | Y | Pressure vessel | Hydrogen | | 300 | 800 | 100 | | | | | In-house designed and built thermal hydrogen pre-charging autoclave. Can be used for static loading experiments (i.e. bolt-loaded specimens) |

## 18. Warwick Manufacturing Group

| WMG | | Material Type | | | Environment hardware | | | Environmental parameters | | | | Mechanical parameters | | | Brief description of equipment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Link** | https://warwick.ac.uk/fac/sci/wmg/ | Metallics | Composites | Polymers | Environmental Chamber | Atmosphere | Hollow specimen compatible | Temperature (K) | | Pressure (bar) | Temp. rate (K min$^{1}$) | Load capacity (kN) | Frequency (Hz) | | |
| **POC** | l.w.figiel@warwick.ac.uk | | | | | | | Minimum | Maximum | Maximum | Maximum | Maximum | Maximum | Minimum | |
| Transport | Permeation, diffusivity | N | Y | Y | Pressure vessel | Hydrogen | | 273 | 333 | 200 | | | | | |