Structural Integrity

Theme lead: Professor David Knowles

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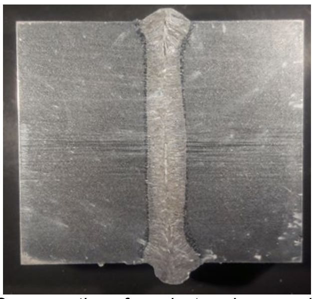
David's research interests are in the area of mechanical properties of materials and their interrelation with the structural integrity of components. Specifically, much of his work addresses mesoscale deformation of materials and its relation to fitness for service of static and rotating components operating in the energy sector.

Theme summary

In safety-critical industries like nuclear energy, expert experimental and theoretical knowledge is vital to underpin physical assets and equipment over its long lifetime. Structural Integrity covers the investigation of engineering materials and components to help support their successful performance in industrial applications.

Research in this area includes:

- Damage-tolerance characterisation (e.g. fracture, fatigue, corrosion, creep and their interaction) for nuclear plant lifetime assessment
- Advanced multi-scale characterization methods (e.g. microstructure, residual stress measurement)
- Modelling and simulation of structural materials and components



Cross-section of an electron-beam weld in nuclear pipework.

As the current EDF fleet of Advanced Gas-cooled Reactors reach the end of their expected plant life and few new build projects underway, life-extension assessments are vital to securing a low-carbon energy supply in the UK. Accurate modelling, testing and analysis helps to ensure nuclear plants can run safely for as long as possible, or be taken offline when necessary to avoid safety issues.

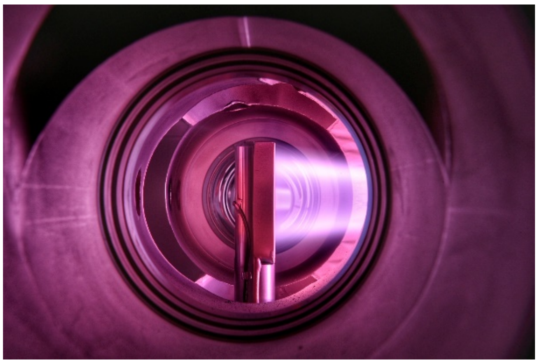
With the UK looking to develop and build the world's first commercial nuclear fusion reactor by 2040, there is a need for expertise in understanding the behaviour of structural materials at very high temperatures and in the presence of a magnetic field. Transferring existing knowledge from fission applications will be vital to meeting the engineering requirements for this challenging target.

Research capabilities and facilities

High Temperature Engineering

Key academics: Professor Mahmoud Mostafavi, Professor David Knowles, Professor Christopher Truman, Dr Harry Coules

We research the high-temperature integrity of materials in nuclear applications, including steels, superalloys and graphite. We are expanding the work we do in respect of other harsh environments, such as high pressures and corrosive materials. Our access includes UKAEA's Materials Research Facility (MRF) at Culham and the High Temperature Facility (HTF) Alliance facilities in Warrington. We also have excellent links with the Henry Royce Institute and expect to be a major user of the new Royce facilities as they come online.



Credit: EUROFusion

Case Study

EDF High Temperature Centre – Established in 2008, the HTC carries out research into nuclear structural integrity issues pertaining to EDF's fleet of Advanced Gas-cooled Reactors in the UK. HTC research focuses on creep, fatigue damage and residual stress challenges to support plant lifetime extensions, through inclusion of knowledge into the R5 high temperature assessment procedure.

Manufacturing

Key academics: Dr Harry Coules, Dr Nicolas Larrosa

We work to improve advanced manufacturing process and the impact that they have on material properties. Metal Additive Manufacturing (AM) is a particular area of interest: large-scale AM for high-integrity applications in the energy industry, and the failure mechanics of novel AM lattice structures have been recent focusses. The mechanics of AM samples can be investigated using small- and large-scale mechanical testing, microscopy and 3D scanning/metrology. We also model key manufacturing processes including welding, AM and forging to predict the effects that they have on material microstructures and residual stress.

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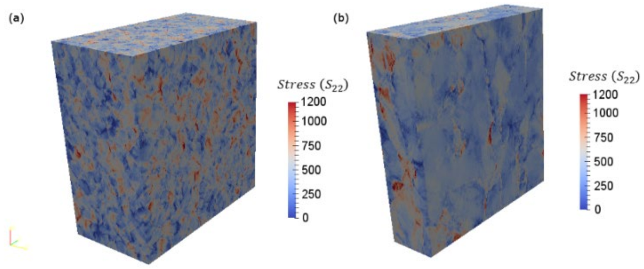
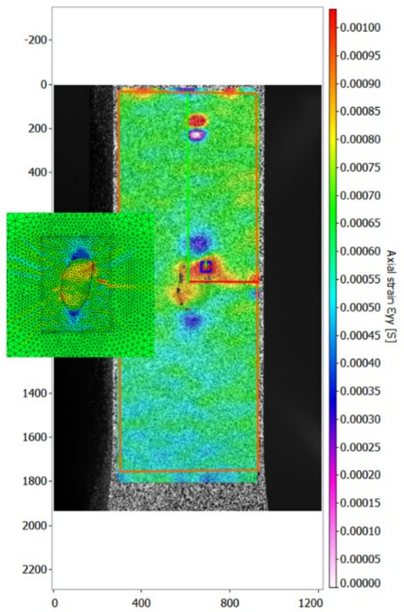
Modelling

Key academics: Professor Mahmoud Mostafavi, Dr Harry Coules, Dr Nicolas Larrosa





The development of a mechanistic understanding of the behaviour of materials in aggressive environments (e.g. a nuclear reactor core) requires appropriate linkages between different time- and length-scales. Modelling of these conditions involves concurrent simulation of multiple interacting and competing physical processes. Carrying out modelling of such situations requires appropriate material properties characterisation at each level of analysis.

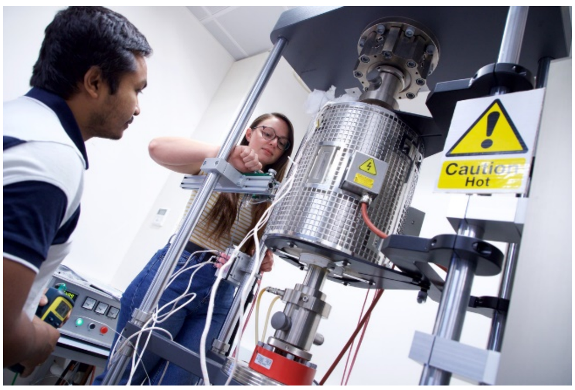
Of particular relevance to the nuclear industry are our micromechanical testing capabilities and associated modelling expertise, We can measure the mechanical properties of very small samples of highly irradiated materials and then "scale up" the results to help predict macro-scale behaviour of engineering components.

This research helps define and solve industrially motivated problems, resulting in well-established close and productive partnerships with a range of companies in the energy, transport and manufacturing sectors. Our modelling activities are supported by the University of Bristol's leading High Computing Facilities, including BlueCrystal.

Facilities

Creep Laboratory

The creep and high-temperature laboratory is a dedicated facility in a temperature-controlled environment, used to support research on understanding the behaviour of metals operating at high temperatures. We operate a suite of computer-controlled servo-hydraulic and constant-load machines permitting tests on metals at temperatures up to 1000°C. This includes novel capabilities for creep-fatigue and high-temperature tests with Digital Image Correlation, including small-punch testing.



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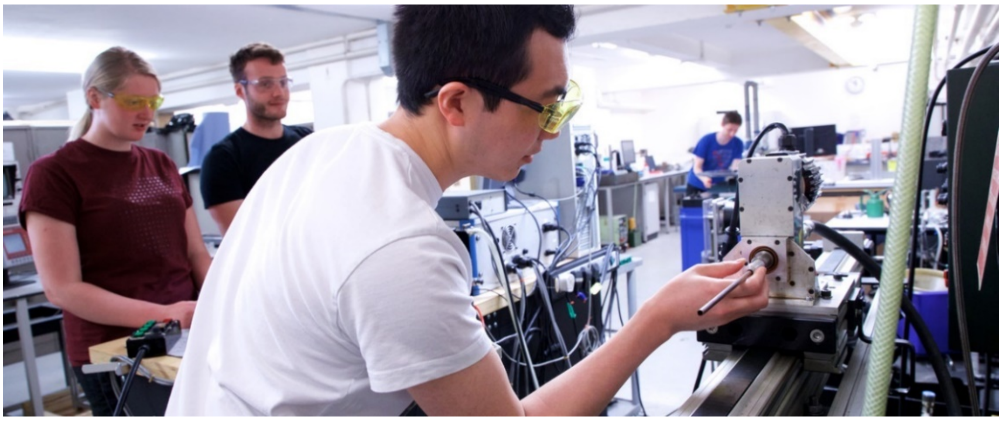
SOUTH WEST NUCLEAR HUB

Residual stress and DIC laboratory

The residual stress laboratory is a facility for measuring residual stresses within engineering-scale components. It was jointly created by the Solid Mechanics Research Group and Veqter Ltd., a company spun-out from the University of Bristol which undertakes projects for industrial clients.

The lab has capabilities for Deep Hole Drilling (DHD), Incremental Centre Hole Drilling (ICHD) and X-Ray Diffraction (XRD). Many residual stress projects are associated with determining residual stresses in high integrity components for the nuclear and oil & gas industries, although we can also measure residual stresses in non-metallic components such as fibre composites for aerospace applications.



Full-field mapping is a very effective way to study and quantify deformation and failure processes in materials, and we operate a specialised suite of DIC systems. Using advanced measurement techniques, in combination with image processing software and finite element modelling, we provide a truly integrated approach to materials assessment and characterization; for example, corrosion defect strain mapping by DIC and Image-based Finite Element Analysis (FEA).

We are particularly active users of UK and international multiuser neutron and synchrotron facilities and in-house X-ray tomography systems. We combine the large datasets acquired from these facilities, along with FEA, to help solve industrial problems.

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