Engineering *Precisely*

A National Measurement Newsletter

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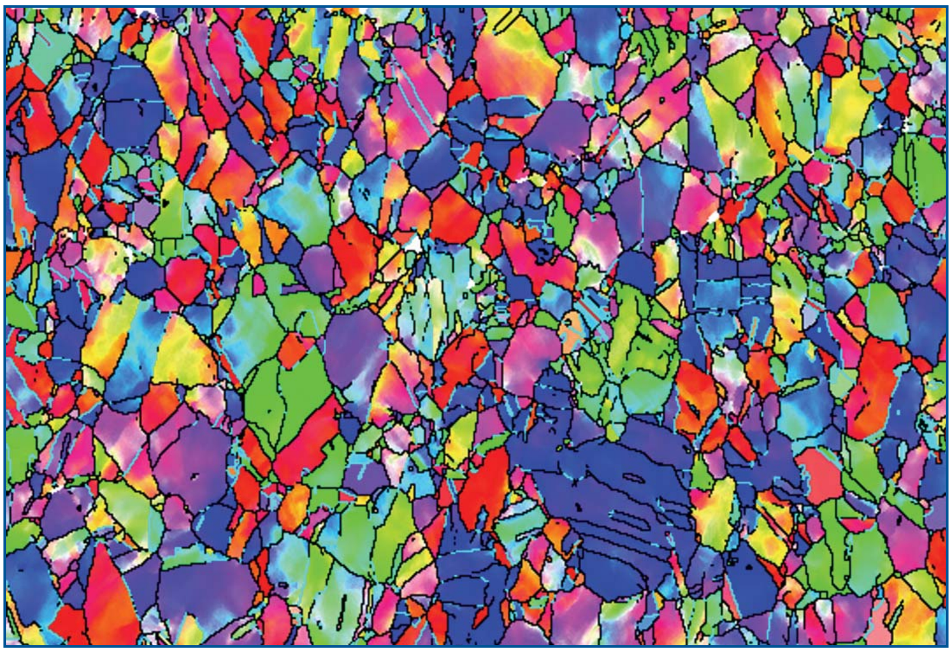


EBSD map of a hot deformed stainless steel sample showing crystallography and grain size

Contents:

Worth a closer look

NPL is working in partnership with the Universities of Wales, Swansea and Sheffield to reconcile Electron Backscattering Diffraction measurements with optical microscopy.

The use of Electron Backscattering Diffraction (EBSD) to characterise the structure of many materials including metals, ceramics and minerals, has grown rapidly in the past five years. With a Scanning Electron Microscope and an appropriate detector, maps of the grain structure over large areas can be generated automatically. This enables quantitative assessment of the effects of manufacture on microstructure and thus properties such as strength or resistance to fracture.

The technique has many advantages over structure measurements by conventional microscopy, including automation and a substantial reduction in variation between operators. Much greater resolution over optical microscopy is possible but this leads to problems of reconciling measurements made by the two techniques.

A recent NPL publication, *Measurement Note DEPC-MN 037*, describes an investigation of these issues as part of a larger programme to study hot deformation processing of metals (engineering grades of Al, Ti, Ni and stainless steel). The programme has produced models to predict the strain in test pieces which have then been verified by microstructural measurements using EBSD and conventional microscopy.

Further work with EBSD and hot deformation is underway and input is being provided to appropriate standards committees currently addressing this measurement topic.

Copies of the current measurement note or advice on the use of EBSD on your materials can be obtained by contacting Ken Mingard on 020 8943 6558 or ken.mingard@npl.co.uk

FEA: making an impact on car interiors

NPL have been working with Land Rover to improve accuracy in the simulation of impact performance of plastics using Finite Element Analysis (FEA).

Tough plastics used in automotive door trim panels have characteristics particularly suited to applications where accidental impact loading is possible. The material must withstand impact without failure or must limit the force level sustained by other objects in the impact event. In other words, the component should minimise damage to the human body part involved in the impact. The ability to confidently predict the response of a plastics product under impact loading is therefore an important aspect of product design in order to optimise safety and reliability in their performance.

An in-depth study of the deformation of two Land Rover door trim subcomponents made of a rubber toughened propylene copolymer, has enabled NPL to evaluate the use of FEA simulations in predicting the deformation behaviour of tough plastics. The factors that may limit the accuracy of simulations include obtaining reliable material parameters; understanding the predictive accuracy of different models that are available; sensitivity to input parameters; rate-dependent behaviour; and influence of element types. All these factors were investigated as part of the research.

The experimental work demonstrated the limitations of the von Mises and linear Drucker-Prager models which are both currently available in FE packages. A new model that takes account of the influence of cavitation on plastic deformation was found to predict most closely the experimental observation.

A new NPL good practice guide; *Prediction of the impact performance of plastics using finite element methods (GPG 87)*, has been produced as a result of the work and is now available from NPL. The guide covers test methods for the determination of property data and parameters required by the three elastic-plastic materials models as well as the basics of setting up an FE analysis for modelling impact.

For further information please contact Louise Crocker on 020 8943 6798 or louise.crocker@npl.co.uk

FEA Simulations

FEA software was used to run simulations of the experimental tests to evaluate the use of such software in predicting deformation in tough plastics. An FE mesh of the toptrim component is shown (figure 1).

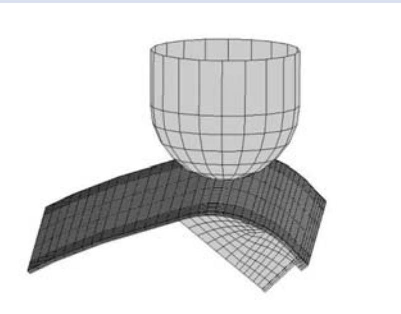


Figure 1: Finite element mesh of the toptrim component

Three different elastic-plastic materials models were used to represent the behaviour of the tough plastic material. Two of the models (von Mises and linear Drucker-Prager) are already available within FEA software packages. The third model was a cavitation model developed at NPL. Working with Oxford University this was coded into the ABAQUS finite element system. The cavitation model is based on the linear Drucker-Prager model but takes into account the formation of cavities within the polymer under loading conditions where there is a tensile component of stress.

The simplest model (von Mises) gives the poorest prediction of the component deformation. The more complex linear Drucker-Prager gives an improved prediction, while the cavitation model prediction is very close to the experimental data (figure 2).

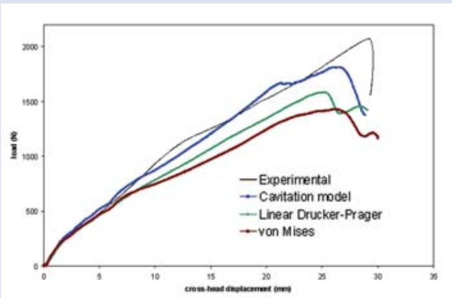


Figure 2: Comparison of measure force-displacement curve for the toptrim component with curves predicted using the von Mises, Linear Drucker-Prager and cavitation models

Figure 3(a): Photograph of the underside of the toptrim component taken at 20 mm displacement.

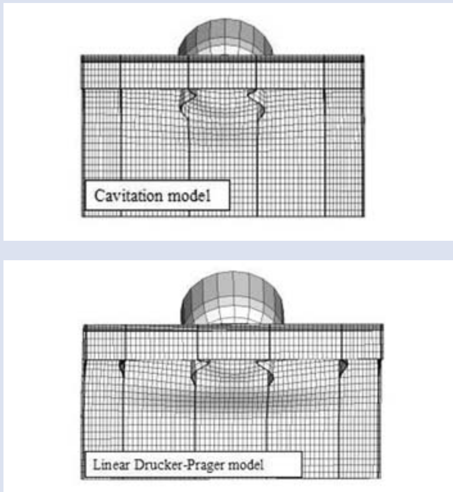


Figure 3(b) & 3(c): Displacement plots (for 20 mm) predicted using the linear Drucker-Prager and cavitation model

Force-displacement plots

Force-displacement curves obtained from loading tests on toptrim components are shown in figure 4.

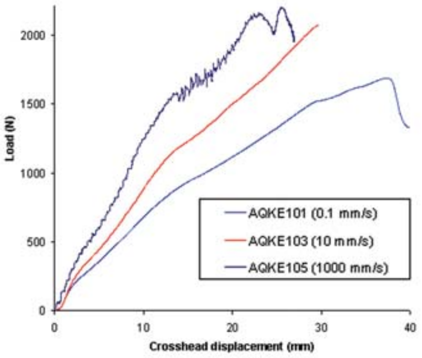


Figure 4: Force displacement plots obtained from the toptrim component at three rates

The forces reached during loading increased with loading rate. Three changes in slope are visible in the force-displacement curves. These ‘kinks’ appear consistently in data from all components tested. Components were also photographed to monitor the degree of component deformation and ascertain the cause of the kinks observed in force-displacement curves.

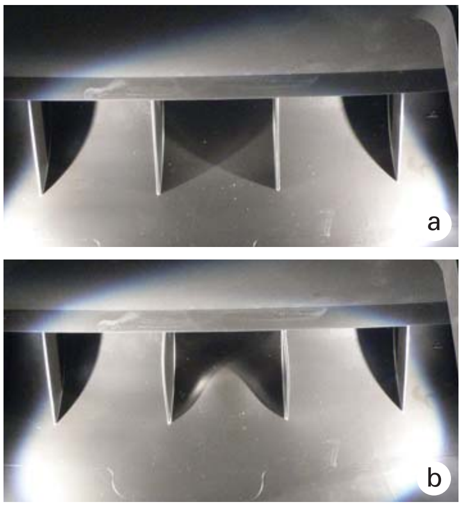


Figure 5: Photographs of the underside of the toptrim component; (a) was taken at the start of the test, (b) after 2.5 mm displacement.

The first kink at approximately 2 mm was found to relate to the onset of bending of the main central ribs (figure 5).

The second kink occurs at a displacement of about 13 mm. It was thought that this would tie in with the onset of deformation of the next pair of ribs. The photographic evidence suggests that contrary to this, the change in slope actually occurs due to a change in the deformation rate of the central ribs. After 12 mm indentation, the central ribs had reached the deformation stage (figure 6a). A further indentation of only 2 mm caused a marked increase in bending of the central ribs (figure 6b). The third kink, which occurs at a displacement of approximately 28 mm, is due to the initiation of tearing at the base of the central ribs (figure 6c). This tearing continues with further indentation.

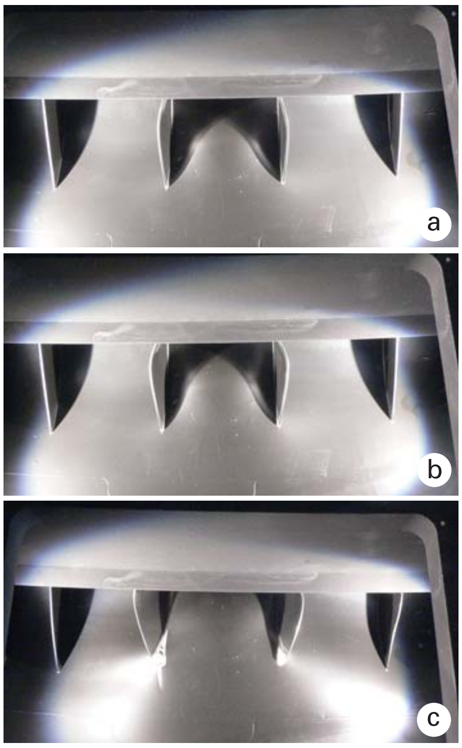


Figure 6: Photographs of the toptrim taken after (a) 12 mm, (b) 14 mm and (c) 28 mm

Examination of the photographs from different toptrim components showed differences in the deformed shape of the ribs. This is illustrated in figure 7 where the left hand rib bends in opposite directions (figures 7a and 7b). When the force-displacement curves obtained from these two components are compared (figure 7c) minimal difference is found between the curves indicating that the actual deformed shape of the ribs is not important.

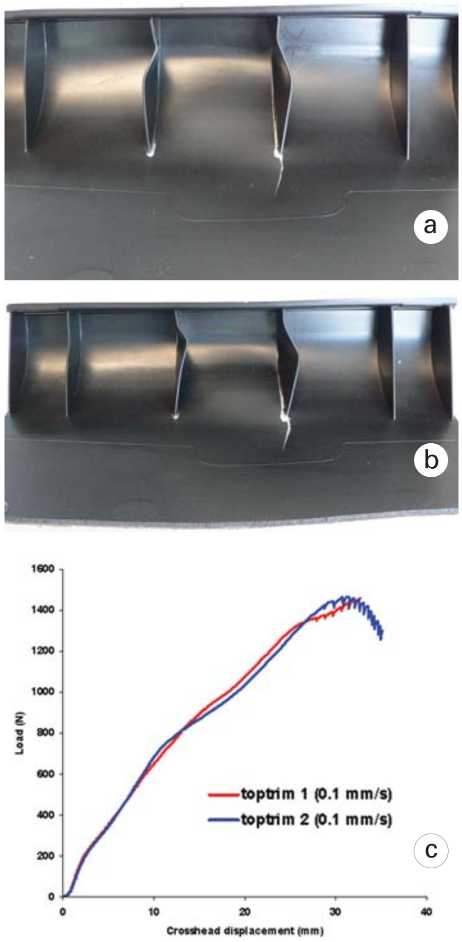


Figure 7: Photographs of two toptrim components (a) and (b) after testing. The graph (c) shows the force-displacement data obtained from these two components.

Visual images of the predicted deformations of the component were compared to the photographs taken of the actual components. At 20 mm displacement photographs show that the central ribs of the toptrim component are highly deformed, while the other ribs are still straight (figure 3a). Deformed plots obtained from the simulation at 20 mm displacement show that the cavitation model correctly predicts the deformation of the ribs (figure 3b). However, the linear Drucker-Prager model wrongly predicts that the outer ribs also deform at this displacement (figure 3c).

At 28 mm, the cavitation model again gives the prediction closest to that observed experimentally. The linear Drucker-Prager predicts deformation in the outermost pair of ribs. Experimentally no deformation was observed in these ribs. In the force-displacement curve, this displacement is associated with the drop in load and is caused by tearing of the central ribs.

How would you spend £6.5m?

The DTI is investing over £6.5m in the Materials Metrology Programme due to start in 2007. Your help is required to define the content and reach of the programme.

Bill Nimmo, Materials Programme Formulator at the National Physical Laboratory (NPL) says “this is an excellent opportunity for UK industry to tell us their metrology needs and assist in directing £6.5m of investment to meet their measurement requirements.”

The DTI is implementing a new formulation process designed to be much more inclusive of UK industry and develop a partnership that will enable industry to create new and improved materials and processes that deliver real benefits.

The new funding combines previous Materials Performance, Characterisation and Processing programmes into one. This will enable companies to create new and improved materials and processes that deliver lower costs, higher quality products and services and improvements in quality of life and trade.

Getting your voice heard couldn’t be easier. Submit your views at: www.npl.co.uk/formulation/materials/2007plus/interest.html

Alternatively e-mail us at MP2007@npl.co.uk; or speak directly to Bill Nimmo on 020 8943 7141

Who standardises the standards?

NPL contributes to standardised measurement around the world, but we need your help to find out where we can be the most effective.

NPL is active on all the necessary international metrology committees, but there may be important standards committees of which we are unaware. This is where readers of Engineering Precisely can help. NPL is interested to hear of any situations where ‘UK plc’ is disadvantaged either due to not having a voice on an international standards committee, or where there is a national committee that would benefit from attendance from an NPL metrologist. We can’t promise to send an expert to each and every committee, but we do need your input to inform us of committees where our time would be most effective.

For more information on the committees where we are active, or to suggest an area where we may be able to help, please contact Andrew Lewis on 020 8943 6124 or andrew.lewis@npl.co.uk

Improved inspection system brings cost benefits

Finding a better way to check for defects in plastic components helped a company achieve significant cost savings by reducing rejects and cutting the time managers spent troubleshooting.

Based in Braunton, North Devon Electronics (NDE) manufactures and assembles coil-winding products. It makes diesel injection coils for the automotive industry.

NDE relies on steel or moulded plastic components which require careful inspection. On some plastic components, tiny positional errors on a group of 1 mm diameter holes had caused failures. The company was keen to bring this under control, but traditional probes couldn’t be used to inspect flexible plastic moulded components.

Following a consultation with a specialist from the National Measurement System, it was agreed a non-contact inspection system could provide the solution. This involved installing a camera and new software on NDE’s existing Coordinate Measurement Machine (CMM), at a cost of around £17k. Resultant annual savings were calculated at £15k.

“Our customers’ expectations are very high and we are committed to maintaining high quality,” said NDE quality manager David Tucker. “The trial certainly made us think about how we could improve the inspection process.”

Non-contact methods and vision inspection are increasingly being used for dimensional measurement. DMAC, the dimensional measurement awareness community within EMAN (Engineering Measurement Awareness Network) are looking to organise a technical meeting on this topic in Autumn 2006.

If you are interested in participating in, or attending a meeting that will discuss the latest technologies and applications in this area please contact Odette Valentine, odette.valentine@npl.co.uk or visit www.npl.co.uk/eman/meetings

Dynamic measurement gets going

Taking measurements of a dynamic system, on a machine calibrated statically, introduces a set of specific problems. NPL is working to solve these problems, and provide a realistic test environment.

The vast majority of measurement instruments are calibrated with reference to a static input signal, whether temperature, force, pressure or any other quantity requiring measurement. When in use, however, such instruments will almost always be measuring a changing quantity. In some cases the rate of change is relatively small but in a number of cases it can be extremely rapid - i.e. dynamic.

Measurement instruments or transducers calibrated statically do not necessarily behave in the same way when subjected to dynamic inputs. This may be due to the frequency response of the instrumentation, creep or drift effects, or to mechanical inertia. This applies to many transducers used to make important industrial measurements. There are often no suitable dynamic calibration facilities available so the user is forced to rely on this static calibration data.

NPL has consulted a group of experts, from a range of industrial sectors concerned with dynamic measurement problems, in order to identify the specific issues. For example, mass transfer rate (solid and multiphase flow) was identified as one area where lack of traceable dynamic measurements was important.

As part of the project, NPL will develop equipment to generate cyclic pressure to allow evaluation of dynamic pressure sensors used in both combustion and aero engines. Plans also exist to develop a device for generating fluid waveforms to measure the response of cardiac output instruments.

In collaboration with other European NMIs, this project has been set up to work in partnership in the area of dynamic force measurement.

To find out more about the NPL's dynamic measurement project contact Stuart Davidson on 020 8943 6224 or stuart.davidson@npl.co.uk

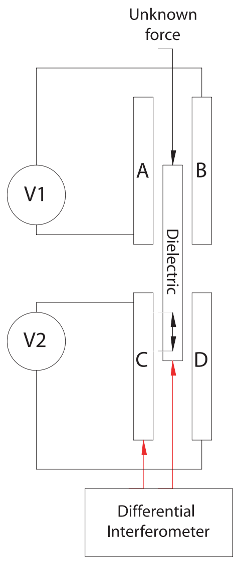
NPL develops a primary balance for measuring forces down to 1 nN

Most measurements that involve mechanical contact on the micro- to nanoscale will have interaction forces that are, at best, ill defined, at worst unknown. NPL is now very active in the area of low force metrology.

Traditionally, the traceability route for force measurement has always been the force generated by a known mass in a known gravitational field. However, for forces below 10 μN (equivalent to a mass of approximately 1 mg) the uncertainties in weighing are too high and the masses are too small to conveniently handle. For such small forces, however, there is the possibility of traceability via electrical and dimensional measurements.

Using a simple parallel-plate capacitor, the force between the plates is related to the capacitance and the voltage between the plates. However, as the plates move apart, the capacitance change is non-linear. By considering the motion of a dielectric between two electrodes, NPL Scientists were able to find a linear relationship.

The NPL-designed primary low force balance uses a laser interferometer to measure the position of a dielectric blade, referenced to the bottom surface of two electrodes, as it moves between the capacitor electrodes due to the applied force. A feedback system applies a voltage between the capacitor plates to provide an equal and opposite force to move the blade back to its null position. The force applied can then be calculated from the voltage applied by the servo system and the known rate of change of capacitance. The dielectric blade is constrained to move in a straight line by a complex flexure arrangement, designed and constructed by the Technical University of Eindhoven. The design of the flexures is such that the force needed to move the blade a distance equivalent to the resolution of the interferometer (50 pm) is less than the design resolution of the instrument (50 pN).



Schematic of the NPL low force balance

Low force measurement has a wide range of applications, from medical applications to the development of thrust balances for space propulsion system.

For further information on the low force balance and its applications please contact Richard Leach on 020 8943 6303 or richard.leach@npl.co.uk

A long time in length

April 2006 marked the end of an era at NPL as it saw the completion of the 44 year long metrology career of Nigel Cross.

For many of the readers of Engineering Precisely, Nigel's name is synonymous with engineering expertise. There can be few engineers and scientists who have used NPL's enquiry service without, at some point, being routed to Nigel's telephone, to be greeted with a cheery voice and sound advice.

Nigel's career in metrology started in 1962 when he joined NPL as an engineering apprentice. Since then he has worked in several parts of NPL, including Engineering Services, Special Projects group - Ship Division, Electrical Science, Mechanical and Optical Metrology, and spent some time in outside laboratories such as the National Engineering Laboratory and RAE.

Nigel has applied his engineering expertise to a wide range of scientific problems and innovations including extensometry, infra-red, H_2O, CO_2 and HCN lasers, infra red radiometers, Josephson Junctions, CMM metrology, measurement of music instruments and determination of the velocity of light. Most recently, during his time in the Length group Nigel was also an active facilitator within the Dimensional Metrology Awareness Club.

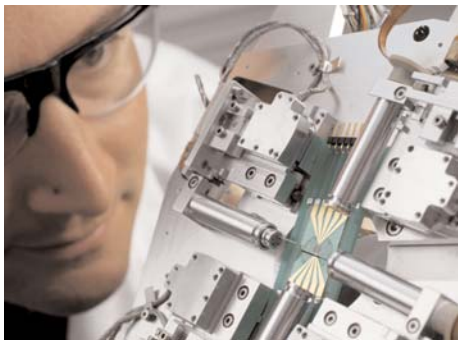
Projects Nigel has worked on for customers outside NPL reflect the wide range of expertise and trust that Nigel has built up over the years. Companies benefiting from Nigel's expertise include: GEC, JET-Culham, ESA, Kodak, RAL, British Aerospace, Marconi, UCL, the National Lottery and Renishaw, to name but a few.

Nigel will be sorely missed at NPL, and we wish him all the best.

CEMMNT - helping 'small' get big

As nano-engineering moves towards ever-smaller scales, the need for accurate measurement grows bigger. A key partner in the Centre of Excellence in Metrology for Micro and Nano Technologies, NPL is helping establish the UK as a world leader in MNT metrology.

The Centre of Excellence in Metrology for Micro and Nano Technologies (CEMMNT) is part of the MNT network, and brings together five globally recognised market-leading organisations that are ideally positioned to supply micro and nano-metrology and characterisation services to UK industry. Alongside NPL are Qinetiq, Taylor Hobson, Coventor and The Systems Engineering Innovation Centre.



CEMMNT aims to investigate and develop techniques that will underpin the manufacturing and commercialisation processes associated with MNT-based technologies. These techniques will enable in-process metrology and characterisation systems for monitoring process parameters and, thereby, maximise yield, minimise waste, improve efficiency and reduce product costs.

Between the five partners, CEMMNT will provide access to new MNT measurement facilities including characterisation of nanomaterials and functional performance; function relevant characterisation of microsystems; surface characterisation of complex micro and nano forms; and systems characterisation for MNT device and systems manufacture.

Training is a core part of CEMMNT, and the centre will establish a teaching ground for new resources, provide training in measurement equipment use and interpretation of the results and short courses on systems engineering.

To find out what CEMMNT can do for you contact Bill Nimmo on 020 8943 7141 or bill.nimmo@npl.co.uk

Thermal Imaging of Solid Oxide Fuel Cells

For the first time in-situ thermal imaging measurements can be made on working solid oxide fuel cells.

Fuel cells use oxygen and hydrogen, or other fuels, to create electricity. Electrons are transferred from the hydrogen to the anode of the cell and then sent as electric current through an external load to the cathode, where they ionise the oxygen. The circuit is closed by ions travelling between anode and cathode through the electrolyte. The ions then react to produce water, the only by-product.

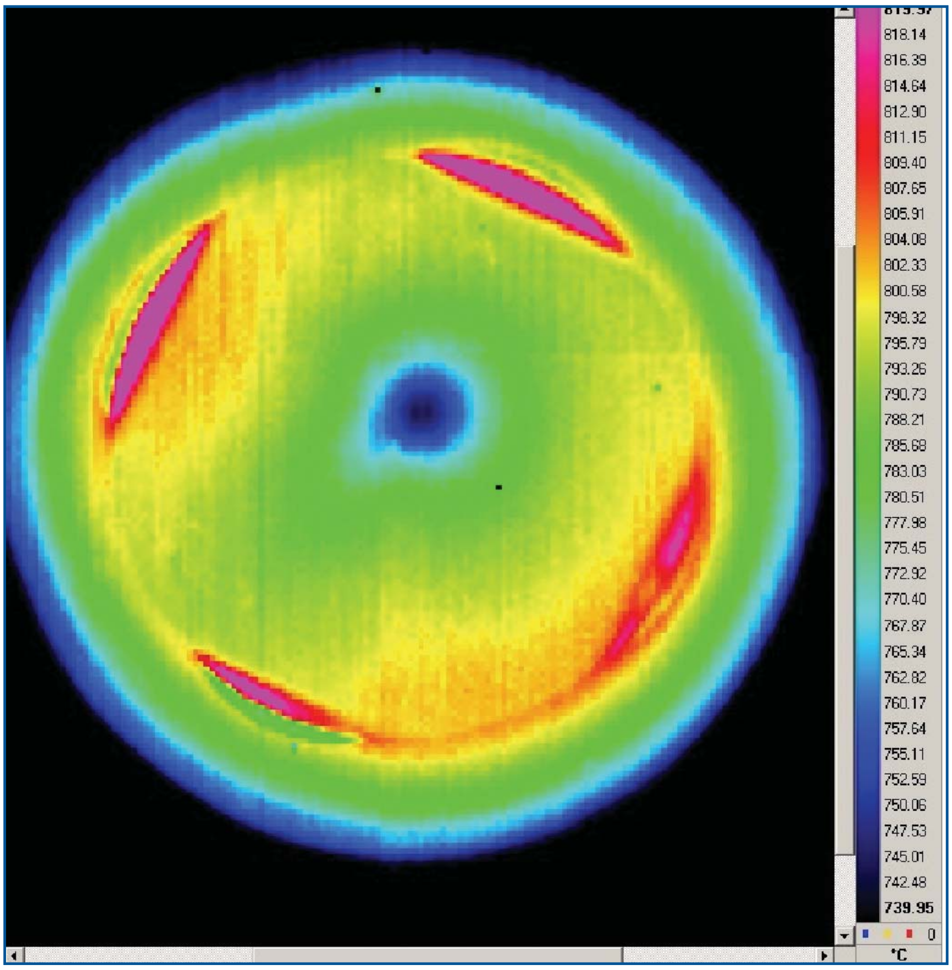
At high temperatures ceramics become conductors for oxygen ions and can act as the electrolyte. Fuel cells made from ceramics are called solid oxide fuel cells (SOFC). They are immune to the most common fuel contaminants but need long start-up times to reach their operating temperature. Their main application is likely to be stationary cogeneration, e.g. domestic or small industrial combined heat and power systems, grid support and uninterruptible power supplies.

In the manufacturing process, the cells require a complicated sequence of heat treatments. With better understanding of the thermal response of SOFC, the rate of this sequence can be increased, and yield improved. During operation, the cells undergo thermal stress due to initial warm-up, exothermic fuel oxidation, endothermic fuel reformation (in some cases), and heating due to the electric current. The resulting complicated distribution of heat and electric power is currently poorly understood.

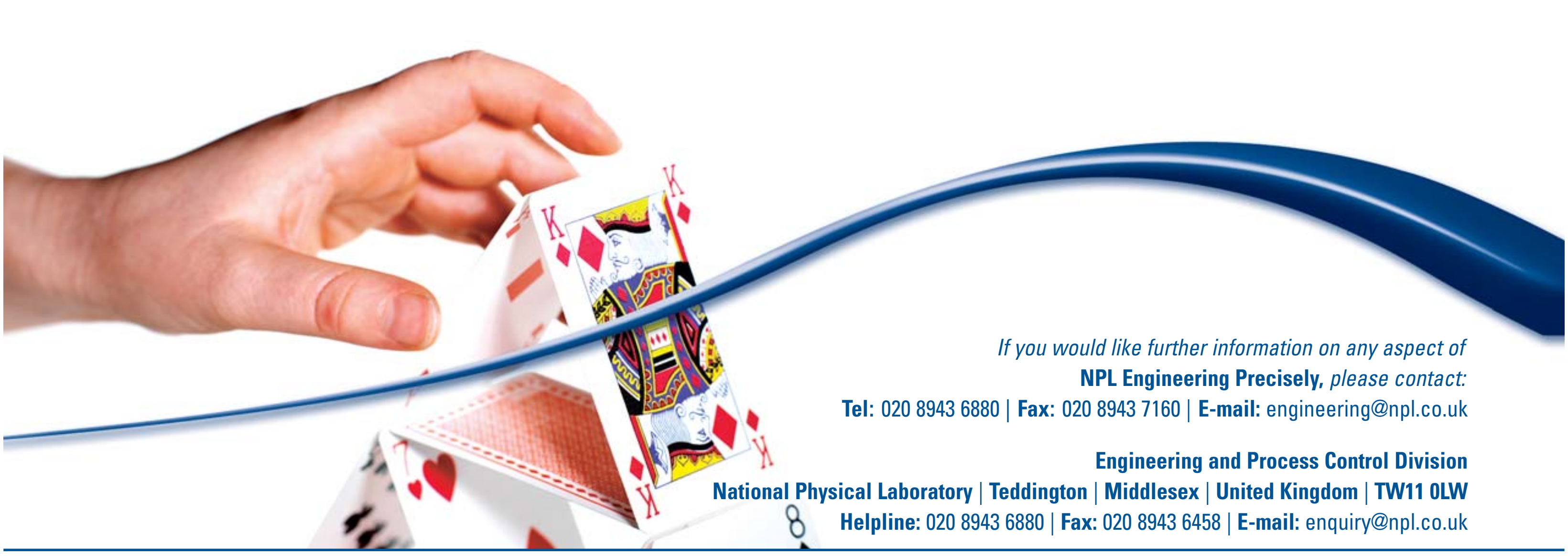
Temperature gradients across SOFC are a major cause of failure both during production and use. They can result in delamination of the electrodes from the electrolyte or cracking of the ceramic electrolyte. As a first step to improved understanding, investigations of freestanding SOFC materials under controlled thermal gradients have been made. Samples consisting of ceramic electrolyte material and both electrodes attached to either side are heated to their operating temperature in a furnace. A temperature gradient is applied by blowing cold nitrogen gas at a controlled flow rate to the centre of the sample, while monitoring the temperature distribution from the other side of the thin sample.

Curiously, the plain electrolyte is almost transparent to infrared light. In contrast, the electrode material strongly emits thermal radiation and gives a clear infrared image. The hot furnace wall (850 °C) shines through the thin, partly transparent electrolyte plate in four segments. Inside of these segments, the anode and cathode have been painted onto the electrolyte in a 4 cm x 4 cm square. Using the cold nitrogen flow technique, temperature differences can be as large as 50 °C over a length of only 2 cm. This temperature gradient is significantly larger than that set as a design constraint by most commercial SOFC developers, indicating that more extreme modes of operation should be tolerable based on thermally induced stresses. It was found that even after repeated cycling of this gradient, the sample had not suffered any damage. However, when fuel was added, the complex interaction between temperature, stress and redox reactions led to fracture. These initial measurements are very encouraging for the planned work on operational SOFC and are the first step to improve the understanding of their complex thermal behaviour.

For more details of the project please e-mail the MET enquiry point: met@npl.co.uk or look at the website: www.metprog.org.uk/energy/



Infrared image of a Solid Oxide fuel Cell with controlled temperature gradient. No emissivity corrections have been applied.



If you would like further information on any aspect of **NPL Engineering Precisely,** *please contact:*
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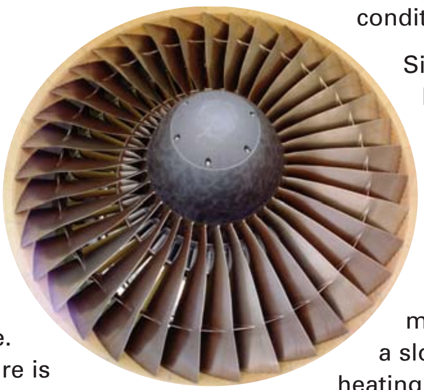
Transient temperature predictions

Many industrial processes have demanding, high temperature environments, such as the manufacture of turbine blades and continuous casting. Material phase changes can significantly affect the material properties and performance of the final components, and a better understanding of the process involved can help save time, money and produce a superior final product.

For the first time, the NPL software packages TherMOL 3D and MTDATA have been successfully linked to provide a powerful software system capable of modelling transient heat transfer, taking account of changes in material properties with changes in temperature and phase. The new hybrid software is also able to model complex 3D multi-material structures subjected to various heat transfer boundary conditions.



Simulations for both the hybrid software and the original TherMOL 3D software were run for a steel block subjected to constant temperature heating. The hybrid model predicts a slower increase in heating as it can take account of the changing heat capacity of the material, whilst the sharp change in gradient at about 10 seconds is as a result of the material changing from the Ferrite to Austenite phase.

To find out more about TherMOL and MTDATA and how they apply to you, visit the websites: www.npl.co.uk/materials/thermol or www.npl.co.uk/mtdata

For further information about transport modelling please contact Simon Roberts on 020 8943 6952 or simon.roberts@npl.co.uk

Forthcoming events

14 September 2006, NPL, Teddington
2006 Time & Frequency Club Meeting
www.npl.co.uk/time/club/meeting6

18 September 2006, NPL, Teddington
ANAMET Club Meeting
E-mail: joe.bennett@npl.co.uk

19 September 2006, NPL, Teddington
FREEMET Club Meeting: Antenna Course
www.npl.co.uk/electromagnetic/freemet_training.html

2 - 3 October 2006, NPL, Teddington
Optical Frequency Combs for Space - (OFCS)
2 Day International Workshop
www.npl.co.uk/ofcs/
E-mail: ofcs@npl.co.uk

11 October 2006, NPL, Teddington
TMAN meeting - Humidity measurement in industrial gases
E-mail: stephanie.bell@npl.co.uk

12 October 2006, University of Huddersfield
EMAN meeting (DMAC) - 3D Surface Measurement Jargon Busting
www.npl.co.uk/eman/meetings
E-mail: odette.valentine@npl.co.uk

17 - 18 October 2006, NPL, Teddington
Nano-Molecular Analysis for Emerging Technologies II (NMAET II)
www.nmaet.npl.co.uk/
E-mail: charles.clifford@npl.co.uk

24 - 25 October 2006, The Manchester Conference Centre, The University of Manchester, UK
ESIA8 – Throughlife Management of Structures and Components
Eighth International Conference on Engineering Structural integrity Assessment
www.fesi.org.uk/esia8intro.html

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