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MPC NEWSLETTER

Issue 6 - Autumn 2006

The Newsletter of The Materials Performance Centre

In this issue:

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- Corrosion research

EDF

British Energy

NUCLEAR ENGINEERING DOCTORATE SCHEME IS AWARDED

We are delighted that The University of Manchester has been awarded the new EPSRC Nuclear Engineering Doctorate Centre which will be led by the Dalton Nuclear Institute in partnership with Imperial College. The technical scope of the Centre will be broad, but includes "materials" as one of six key themes. The Nuclear EngD will be a four-year postgraduate qualification aimed at the UK's best young research engineers. Its aim is to equip them with the skills needed to take on senior roles within the nuclear industry. As part of the programme, students will complete a Management Diploma from Manchester Business School.

Professor Andrew Sherry, Director of the new Nuclear EngD Centre, says: "The EngD is a radical alternative to the traditional PhD, being better suited to the needs of industry, and providing a more vocationally oriented doctorate in engineering." Up to seventy-five percent of the EngD will be based in industry through partnerships with companies including Nexia Solutions, British Energy, and Rolls Royce.

There will be up to 12 projects awarded per year across the full technical scope. The first intake of students onto the EngD will be in September 2006. Those interested in being involved as an academic supervisor of research engineers should contact The Nuclear EngD Centre for further information, nucengd@manchester.ac.uk

PARTNERSHIP AGREEMENT WITH BRITISH ENERGY

A partnership agreement has been signed with British Energy Generation Ltd. The MPC can now look forward to closer collaboration with BE in the areas of “graphite, corrosion, residual stress measurement and damage characterisation, fracture mechanics (including local approach), creep continuum modelling and Computational Fluid Dynamics and such other areas of mutual interest as may be agreed between the Parties from time to time”. This new partnership is a significant development for the MPC and will help us to work closely with BE to address challenging materials issues for operating reactors.

A formal launch event will take place on 28th September at the Manchester Conference Centre, starting at 11.00. The day will include presentations from British Energy on “Why university links and technical materials challenges?”, from Nexia Solutions on “University Research Alliances” and from the MPC on “Manchester 2015, Nuclear, Materials and Engineering” and “ New Approaches for the Study of Materials in Extreme Environments”. There will also be an exhibition and tours of Materials and Engineering.

British Energy

THE DIRECTOR’S CUT

Welcome to the Autumn Edition of the MPC Newsletter. A number of significant new developments have taken place over the summer. We are pleased to announce the signing of a partnership agreement with British Energy and we look forward to working closely with colleagues at BE in a range of research areas within our continuing and future collaborations. Further details of the partnership are described above.

Also, the award of a new Nuclear Engineering Doctorate Centre, for which I have been appointed director, presents significant opportunities for building a critical skill and knowledge base in nuclear materials science and engineering. The MPC’s staff and students have now taken up residence in our newly completed office suite, located in A11, The Mill. In addition to resources for established colleagues, the space provides three ‘hot desks’ for external visitors and a meeting room. A new addition to the MPC’s capabilities is reported on p7, this multimode computer cluster will greatly enhance the capability in carrying out materials modelling projects within the MPC from atomic simulations to crystal plasticity and solid mechanics. The centre article featured on pages 4 and 5 highlights some of the research ongoing in the Corrosion area, specifically work being carried out under the KNOO programme ‘IASCC and atmospheric corrosion’, ‘Irradiated assisted SCC ’ and also on the theme of corrosion in cement. Finally, we would like to extend our congratulations to Dr Joao Quinta da Fonseca, Dr Haiyan Li and Mrs Gail Scanlon on the births of three healthy baby boys and to Mr Fabio Scenini and Emma on their recent marriage.

WORKING @ THE INTERFACE – INTRODUCING THE A11 OFFICE SUITE

"The single most important factor in shaping the quality of knowledge is the quality of space", Nonaka et al. (2001)

Understanding, assessing and predicting the performance of materials in industrial applications requires input from a wide range of scientific disciplines. If we are to achieve the research progress that we aspire to, it is crucial to attract top quality researchers from a range of disciplines who are able to work creatively and effectively '@ the interface'. This requires an approach to university research which not only reinforces technical excellence within each scientific discipline but also maximises effective interaction across the disciplines.

To create a unique '@ the interface' approach to materials research, we have planned, designed and created a high quality workspace that co-locates about 60% of the MPC. The workspace, located in A11 (The Mill), is consistent with the so-called 'club' model of office accommodation – a model which reinforces the need for both autonomy and interaction within materials research, see figure. The 'club' model supports "high-level work carried out by talented independent individuals who need to work collaboratively" Duffy (1997).

The development of A11, supported by the Faculty of Engineering and Physical Sciences, the School of Materials and Nexia Solutions, has established workstations for academic and administrative staff, research associates, and PhD students, as well as hot-desks for other members of academic staff and visiting scientists from industry and academia (including the new Nexia Solutions Senior Fellows). In addition there are three quiet rooms for those who need to focus on the work-in-hand, a meeting room for up to 12 people, and social space for lunch, coffee and chat.

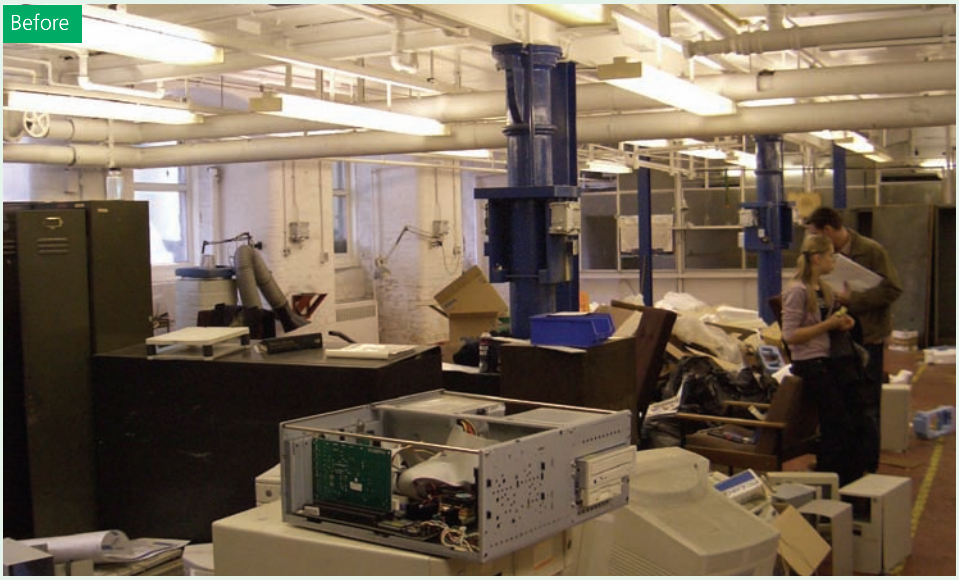
The new A11 office suite has been achieved through persistence, creativity and hard work. Particular thanks go to Mr David André who provided the design concept, and to Mr Paul Jordan and Dr Jane Deakin who worked effectively with the University Estates Department to realise the vision.

Further Reading

Nonaka, I. et al. (2001), Building Ba to enhance knowledge creations: and innovation at large firms, available at www.dialogonleadership.org/Nonaka_et_al.html

Duffy. F, (1997), The New Office, Conran Octopus, London, 1997

Before



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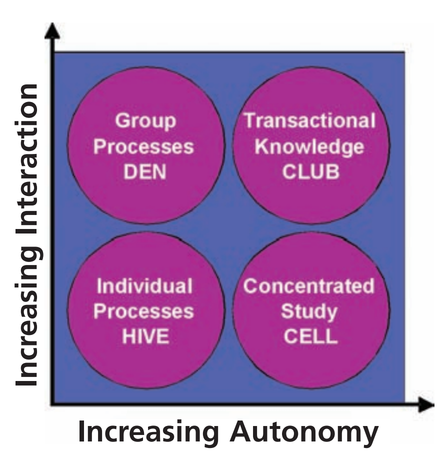


Work patterns and work space, Duffy (1997)

CORROSION RESEARCH IN THE MATERIALS PERFORMANCE CENTRE

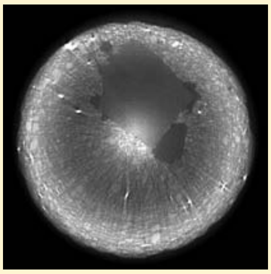
A number of research programmes at PhD and Postdoctoral Research Associate level within the MPC are focusing on corrosion and stress corrosion cracking (SCC) mechanisms in various materials used in the nuclear industry. These cover a wide range of applications and components, from decommissioning and cleanup to current and potential new nuclear plant. Research topics include the long-term corrosion behaviour of immobilised Intermediate Level Waste (ILW), the development of SCC cracks in stainless steels in high temperature water and the long term behaviour of stainless steels in chloride environments. Both experimental and predictive modelling approaches are being used. The focus of much of this research is the development of an improved understanding of the controlling mechanisms of corrosion and SCC of such material-environment combinations, to enable the improved prediction of component behaviour. This article provides an overview of six research programmes which are either ongoing or commencing this year. For further information regarding these and other corrosion research programmes, please see www.materials.manchester.ac.uk/mpc or contact Dr Nick Stevens (nicholas.stevens@manchester.ac.uk).

Project Title: The Corrosion of Mg and Al in Cements used for Waste Immobilisation

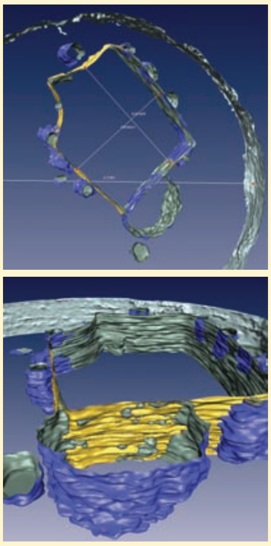
Student: Evripidis Tsaousoglou

The use of cement systems to store intermediate level waste such as Magnox swarf and aluminium legacy wastes is intended to lock up potentially radioactive ions in oxide or hydroxide form. While iron and steel are highly compatible with such systems, more reactive metals such as magnesium and aluminium undergo an initial reaction with the wet cement, until a passivating surface layer grows. The use of Electrical Impedance Spectroscopy (EIS) to follow the corrosion of these metals in Blast Furnace Slag/Ordinary Portland Cement mixtures has been shown to give results in line with those previously found by BNFL research using hydrogen gas evolution measurements to follow the corrosion processes. The electrical technique has the advantage of being an instantaneous measurement, but the disadvantage of being dependant on knowing the surface area of the material under study to calculate the surface oxide thickness exactly. As the initial corrosion of the metals in the wet cement is rapid, hydrogen bubbles are produced at the metal cement interface in the wet cement, and these voids are preserved as the cement cures. While the initial hydrogen gas may diffuse away to be replaced by water vapour, unless the voids fill with liquid water, they will be non-conducting, and will lower the surface area of the metal in contact with the cement phase. To measure this effect, tomographic studies were undertaken at the Swiss Light Source in March 2006, using different cement blends and metal samples. Three dimensional imaging of the cement/metal interface has allowed the proportion of the surface area occluded by bubble formation to be calculated for the different systems tested. Correlation factors of between 20% and 30% are found to be necessary to calculate the active surface area in these systems. The tomographic measurements have therefore allowed the EIS results already obtained to be re-evaluated to fully reflect the growth of the bubble layer around the metals and to eliminate errors because of the changing surface area.

The validation of the EIS technique for studies in cement/metal systems such as those used for Intermediate Level Waste storage will support future work on new cementing systems, across the University Research Alliances and within Nexia. Potential long term developments under discussion include the possibility of building probes into future waste packages which allow non destructive electrical tests such as EIS studies to be performed to investigate the condition of the wasteform.



A two dimensional slice recovered from tomographic analysis of cement samples containing magnesium, showing hydrogen bubbles formed by corrosion during setting.



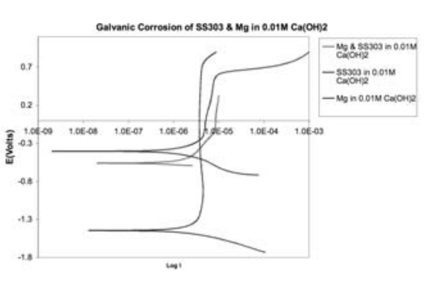
A set of 50 slices divided up into phases in three dimensions showing the bubbles lying at the metal/cement interface. The colour of a surface indicates the phase behind the surface where grey = cement, blue = bubble formed by H_2 evolution, yellow = magnesium.

Project Title: Mechanistic Investigation of Internal Corrosion in Waste Packages

Student: Elsie Onumonu

The general corrosion behaviour of reactive metals such as Mg and Al has been studied in the Materials Performance Centre over the last three years. In real waste products the general rate of corrosion will apply to the majority of waste pieces in a waste package, but the possibility of localised accelerated corrosion processes affecting a proportion of the waste cannot be ruled out. Any material experiencing a microenvironment which differs from the bulk conditions may corrode in a different way. A typical accelerating factor would be bimetallic or Galvanic corrosion, where two different metals in electrical contact in the same electrolyte form a circuit. In such cases the more anodic material will corrode at an accelerated rate. Initial experimental studies have focused on magnesium and steel in calcium hydroxide solutions at pH 12+, reflecting the possible interactions between Magnox cans and the 316L steel used to fabricate the waste drums with the pore water of the cement acting as the electrolyte. An intriguing possibility is that at very high pH levels Mg may passivate more completely than steel and become cathodic with respect to steel rather than anodic.

The next major experimental effort will be to work on the effects of uranium contamination of Magnox swarf, and to perform tests on magnesium/uranium couples and also triply coupled magnesium/steel/uranium systems to see what the corrosion rates and reactions are in the environments found within ILW packages.



Project Title: Electrochemical Cleaning of Metallic Structures.

Student: Guy Woodhouse

The contamination of skips and metal tools used in storage ponds, collectively known as 'pond furniture', could give rise to the transfer of active species between the ponds at power stations, transport flasks used to move material, and receiving ponds at Sellafield. This project has begun with experiments exposing steel samples to inactive Cs solutions formulated to mimic the chemistry of fuel storage ponds. The use of XPS and SIMS has shown that Cs contaminates the steel surfaces even at low levels of Cs in solutions, and also indicates that the equilibrium concentration of Cs is reached within quite short timespans of only a few days. The contamination pattern appears random at the levels of resolution attained so far, and higher resolution nano-SIMS studies are planned, to see both the lateral distribution of Cs and also the depth profile of Cs contamination through the surface layers of the steel. This work has been complemented by work with Professor Francis Livens' group in the Radiochemistry URA laboratory using active Cs solutions, where total Cs uptake levels are being measured using a storage phosphor system to detect the small amount of active Cs which each sample picks up. The tendency of Cs to attach to metal surfaces may be seen as rather counter-intuitive, as Cs is very soluble in aqueous solutions. The contamination mechanism may therefore be one which is coupled with the corrosion processes occurring naturally on the steel surface, in particular the cathodic areas, and experiments exposing polarised steel surfaces are underway to clarify this effect.

Our eventual aim is to allow the mechanism of the Cs contamination to be understood, and to develop accurate methods to monitor such contamination. This may allow simples steps to prevent or reduce contamination to be developed. We also aim to use our experience in characterising Cs contamination to test novel decontaminants being developed at the Radiochemistry URA, and to investigate the effects of electrochemical polarisation on the decontamination process.

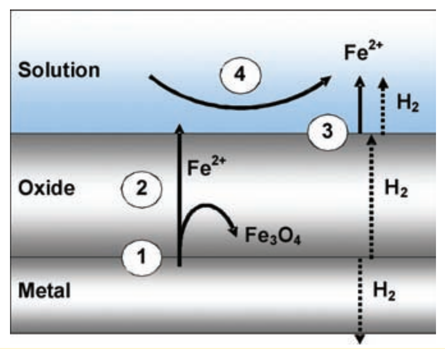
Water bath containing individual steel samples in pond water solutions, held at constant temperature.

Project Title: Flow Accelerated Corrosion Modelling.

Student: Anissa Amimer

In partnership with Electricité de France, the Materials Performance Centre has begun a project to model the phenomenon of Flow Assisted Corrosion (FAC), and to understand the role of the porous oxide layer formed during FAC. Flow assisted corrosion is a particular problem for low alloy steels in secondary water circuits in both nuclear and fossil fuel power stations. It acts by increasing the tendency of the protective oxide layer on the metal to dissolve or become porous, exposing the metal substrate to the solution and leading to wall thinning, and in some cases pipe rupture. The development of an empirically established model by EPRI and within EDF have allowed vulnerable pipe sections to be identified and by a program of targeted inspections, the risk of FAC is managed successfully. These models do not consider the reactions occurring as electrochemical and are therefore not able to reflect the influence of potential on the rate of the corrosion occurring, or to show how oxidising or reducing species can affect the FAC process.

To develop a numerical model to include all the features of the system, the mass transport and homogeneous chemical processes illustrated have been modelled using COMSOL Multiphysics. A simple one dimensional model has reproduced the analytical results of the existing Berge model, and a two dimensional model has been created to allow the effects of precipitation at the pore walls to be studied. Further questions which will be addressed as the project moves into the second year will be to find out the domains within the porous film where precipitiation can occur, and to find how the steady state thickness of the oxide film varies as a function of the rates of the transport processes which occur.



FAC may occur by the following four step process:

1. Iron oxidation at the boundary between the metal and the oxide layer, forming soluble ferric species in the pore solution and precipitating magnetite under the existing oxide film.

   $Fe + 2\,H_2O \Rightarrow Fe^{2+} + 2\,OH^- + H_2$

   $Fe^{2+} + 2\,OH\text{-} \Leftrightarrow Fe(OH)_2$

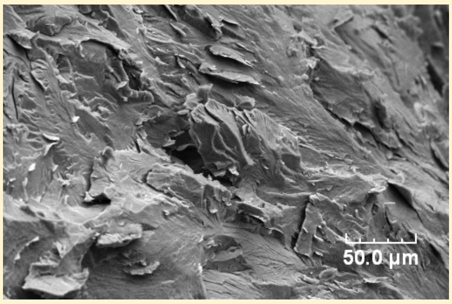
   $3\,Fe(OH)_2 + 2\,OH^- \Rightarrow Fe_3O_4 + H_2 + 2\,H_2O$
2. Iron diffusion in pores in the oxide layer.
3. Dissolution of the magnetite layer from the top, giving soluble species containing ferric ions, possibly complexed with hydroxide.

   $1/3\,Fe_3O_4 + (2\text{-}b)\,H^+ + 1/3\,H_2 \Leftrightarrow Fe(OH)_b^{(2\text{-}b)+} + (4/3\text{-}b)\,H_2O$
4. Transfer of soluble species from the stationary solution in the pores to the flowing solution in the bulk.

Project Title: Chloride-Induced Stress Corrosion Cracking of Austenitic Stainless Steel

Student: Karen Shapiro

In order to investigate how the residual stress profiles within 304 and 316 steel samples influence the growth of cracks, samples with and without residual stresses have been exposed to highly corrosive solutions of boiling magnesium chloride for periods of up to 17 days. The effect of this treatment is to encourage cracks to grow wherever the residual stress profile is at all tensile. By measuring the distribution of crack lengths, and noting how this compares with the residual stress profile going in from the surface, the influence of the residual stress on whether cracks grow or arrest at particular locations can be determined. Initial experiments used mechanical ovalling to produce stress distributions, but more recent work has sought to use only the stresses in as received seamless pipe materials. Control experiments can be performed by removing the residual stresses using annealing treatments, although it has been found that Cr loss in oxygen atmospheres can give undesirable results and increase crack formation, so inert atmosphere furnaces must be used. The use of X-Ray diffraction techniques allows the residual stress profile to be mapped on a sample by sample basis, but future work will use calibrated machining on a computerised lathe to prepare samples with previously established stress profiles, and allow cracks growing from tensile into compressive regions to be studied. It is hoped that if crack arrest points can be matched to the tensile/compressive boundary, then surface finishing strategies to minimise the risk of crack propagation can be demonstrated to be effective.



Fracture surfaces on a stress corrosion cracked ovalled sample approximately mid-way into the wall thickness.

CONFERENCE WATCH

See below for our selection of forthcoming events.

MPC-British Energy Partnership Launch
28 September 2006, Manchester Conference Centre.

International Conference on Structural Integrity and Failure (SIF 2006)

Materials Australia and the Australia Fracture Group
Sydney, Australia 27 - 29 September 2006
www.azom.com/events/EventDetails.asp?EventID=17

Workshop on Advanced Integrity Assessment,
11-13 October 2006, JRC Petten
Bergen, The Netherlands,

Materials Science and Technology 2006 Conference and Exhibition
Cincinnati, Ohio, USA
15 - 19 October 2006
www.matscitech.org

Computational Modelling – COMSOL Users Conference
Boston, Mass., USA 22 - 24 October 2006
COMSOL Software Solutions – Computational Modelling
www.comsol.com/conference2006/3program.php

Ethics in Engineering, FESI.
Manchester, UK. 26 October 2006
www.fesi.org.uk

Materials Technical Group Meeting 'New Developments in Materials and Joining for the Nuclear Industry'
23 November 2006. The University of Manchester.

The 3rd International Conference on Recrystallisation and Grain Growth (ReX and GG III)
Jeju Island, Korea, 10 - 15 June 2007
More details can be found at www.rex-gg-2007.org

International Conference on Experimental Mechanics: Experimental Analysis of Nano and Engineering Materials and Structures (ICEM 13)
Alexandroupolis, Greece, 1 - 6 July 2007
More details can be found at http://icem13.gr

2007 ASME pressure vessels and Piping division conf.
San Antonio, Texas. July 22-26, 2007
www.asmeconferences.org

5th BSSM International Conference on Advances in Experimental Mechanics
4 - 6 September 2007, The University of Manchester, UK

SPOTLIGHT ON... DR STUART LYON

Dr Stuart Lyon is a Reader in Corrosion Science at The University of Manchester, whose research interests span atmospheric corrosion, surface engineering and treatments and the application and development electrochemical techniques. He is an associate scientist in the MPC, and is active in the MPC's contribution to the EPSRC's 'Keeping the Nuclear Option Open' programme.

Dr Lyon's involvement with the nuclear industry goes back before his undergraduate days, when he worked as an intern at Harwell, for the UK Atomic Energy Authority, performing Molecular Orbital calculations in the theoretical physics group. The UKAEA then sponsored Dr Lyon through his first degree studying Metallurgy at Trinity College, Cambridge, including vacation work at Risley and the Dounreay power station.

After graduation Dr Lyon stayed at Cambridge, and undertook a PhD in the field of solid state electrochemistry, which involved the use of a superionic solid state proton conductor, hydrogen uranyl phosphate tetrahydrate, to detect the hydrogen dissolved in metals as a result of corrosion reactions. On receiving his PhD in 1983, the young Dr Lyon came to Manchester to continue his research career.

At Manchester Dr Lyon's research interests have grown around the central theme of atmospheric corrosion. On coated surfaces this entails drawing together the techniques needed to prepare and characterise coatings and study the mechanisms by which they protect their substrate during their life, and how they eventually fail. Dr Lyon also has a strong interest in developing electrochemical methods such as spatially resolved electrochemical impedance, and in electrochemical processes in thin condensates such as form under atmospheric conditions. Current projects in Dr Lyon's laboratory include work on such varied topics as improving the storage of ferrous archaeological artefacts, and work on the optimisation of the corrosion performance of thermal sprayed coatings. Dr Lyon has also built up a substantial interest in corrosion inhibition, and is supervising projects looking at chromate inhibitor replacement, the effect of acetate on the inhibition of mild steel corrosion in CO_2 containing solutions, the development of methods of evaluating the performance of inhibitors in organic coatings, and in novel organic corrosion inhibitors.

Dr Lyon has been a member of the committee of the Corrosion Science Division of the Institue of Corrosion for over 20 years, and recently took on the role of President of the Institute. He is also active in contributing to greater public understanding of science, and has helped develop a kit for primary schools to use to perform simple corrosion experiments.

It could all have turned out differently for Dr Lyon, as he went for an interview for a position at BNFL Sellafield after gaining his first degree.

SUMMER STUDENTS

Over the summer we have been pleased to welcome 9 interns and 6 MSc students to the MPC.

Two students have been funded through our summer internship scheme. Claire Platts, a student from Durham University has been studying 'Band structure calculations of mixed metal oxides' with Dr Nick Stevens and the modelling group within the MPC. Whilst, Joanna Waldie, from Cambridge University, has worked with Dr James Marrow to investigate Observation of Intergranular Cracking by Image Correlation.

Several students joined us from France. They include Xavier Piccino, Julia Falourd, Laura Liroy, Baptiste Soury, Clemance Bourle, Garance Degret and Fabien Leonard. The students worked on a range of themes including 'The preparation and characterisation of artificial pits to study salt layers formed during pitting corrosion', 'Laser speckle interferometry during testing of highly disimilar welds', 'Comparison of x-ray diffraction and EBSD for plastic strain measurement'.

Also, several MSc students have undertaken dissertation projects with academics from the MPC, whilst completing MSc Courses in Corrosion Science and Engineering, Advanced Engineering Materials and Nuclear Science and Technology.

If you would like any information regarding these projects, please contact Dr Jane Deakin (jane.deakin@manchester.ac.uk, or 0161 306 4840).

NEW COMPUTER CLUSTER

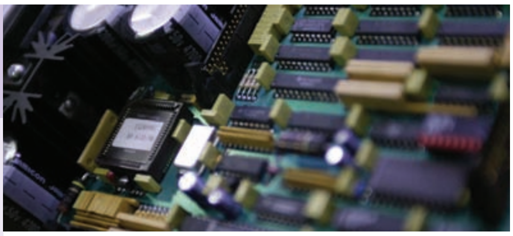
A new computer cluster has recently been installed at the Materials Performance Centre. A computer cluster consists of a number of separate motherboards (nodes) controlled by a master node, which also handles the distribution of jobs. Calculations are performed on the compute nodes, using either one (serial) or multiple (parallel) processors. The new Transtec cluster has ten compute nodes, each with two dual-core Opteron processors, giving a total of forty processing elements. It also has 68GB of fast RAM and 5TB of hard disk space.

This computing environment is a step change in the computational capability of the MPC. The many calculations of simulations that once took too long to be feasible can now be run simultaneously and problems that were once too large can now take advantage of large amounts of RAM and of disk space.

The new cluster opens the door to exciting new research, such as the modelling large, complex multi-scale and multi-physics problems such as environmental assisted cracking. It will make it possible for metal failure models to include the microstructural heterogeneity exhibited by real materials and for aspects of crystal plasticity and dislocation dynamics to be introduced to current approaches.

Finite Element modelling is a core MPC capability that will be significantly enhanced by the new cluster, which will enable finer meshes and thorough parametric studies. The new cluster is also a great boost to the ongoing activity in fundamental computational modelling, where material behaviour is studied at the atomic scale. Ongoing projects include the simulation of diffusion along grain boundaries using molecular dynamics and the kinetic Monte Carlo modelling of materials chemistry and defect structure evolution, using information from molecular dynamics.

The cluster is now being commissioned and should be available to all MPC investigators by the end of September. Contact Andrew Willetts (Andrew.willets@manchester.ac.uk) for further details.



NUCLEAR SCIENCE QUIZ

Test your knowledge and visit our website www.materials.manchester.ac.uk/mpc. to find the answers.

1. Where did the majority of the radioactivity in the earth come from?

A. Cosmic rays
B. Nuclear reactors
C. Supernova explosions
D. Atomic weapons

2. What is the SI unit of radioactivity?

A. The Curie
B. The Rad
C. The Sievert
D. The Becquerel

3. Which of these three would be a hazard to you if you were standing 1 metre away from a drum of highly radioactive waste?

A. Alpha
B. Beta
C. Gamma

4. What effect will a strong flux of gamma radiation have on a 1”thick steel plate after 5 years

A. Causes embrittlement
B. Softens it
C. Makes it radiaoactive
D. No significant effect

5. Approximately what proportion of the UK’s electricity is produced from nuclear reactors

A. 10% C. 30%
B. 20% D. 40%

6. Approximately what will this figure will be in 10 years time?

A. 5% C. 25%
B. 15% D. 40%

7. What happens to the majority of fuel removed from UK reactors at present?

A. Buried underground
B. Stored above ground
C. Reprocessed and stored
D. Reprocessed and reused

8. How much nuclear fuel gives the energy output of a ton of coal?

A. 100Kg C. 2Kg
B. 10Kg D. 20g

9. What type of nuclear reactor is most commonly used worldwide?

A. Advanced gas-cooled reactor
B. High temperature reactor
C. Boiling water reactor
D. Pressurized water reactor

10. Which of the following contributes most to the annual radiation dose that we typically receive?

A. medical imaging and diagnostics
B. nuclear power
C. fallout from atomic weapons tests
D. natural background radioactivity

RESEARCH OPPORTUNITIES WITHIN THE MPC

Our strong collaboration with industrial partners provides researchers with an excellent launch-pad for future careers. Added Benefits of working with the MPC include:

- Competitive PDRA Salaries
- Enhanced tax-free PhD Studentships
- Industrial placements in Europe and USA
- Industrial and academic supervision
- Interaction with scientific and industrial community at conferences & seminars
- Access to advanced research facilities with the School of Materials and laboratories of industrial partners.
- Enhanced tax-free PhD and EngD studentships

Current Vacancies for October 2006 onwards

A large number of posts are currently available funded by a range of sponsors including EdF, EPSRC, MoD, Nexia Solutions, Rolls Royce and Westinghouse.

PhD Studentships

- High resolution microstructural characterisation of proton irradiated stainless steel
- Mechanistic studies of stress corrosion cracking of Alloy 600 in high temperature water
- Corrosion Studies on Stainless Steel in Nitric Acid
- Residual stresses in oxide layers of zirconium alloys
- Minor PGM metal additions modelling of stress corrosion cracking
- Spent AGR fuel performance
- New mathematical and computational models of polycrystalline deformation

PDRA Posts

- Phase transformations in welds
- Measurement and modelling of residual stress effects in steel pressure vessel components

For more information about these projects visit our website at www.materials.manchester.ac.uk/mpc.

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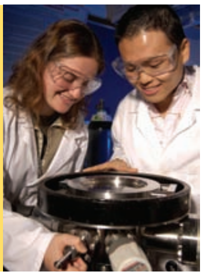

Directions to the University, maps of the campus and further information about the Materials Performance Centre can be found at our website

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