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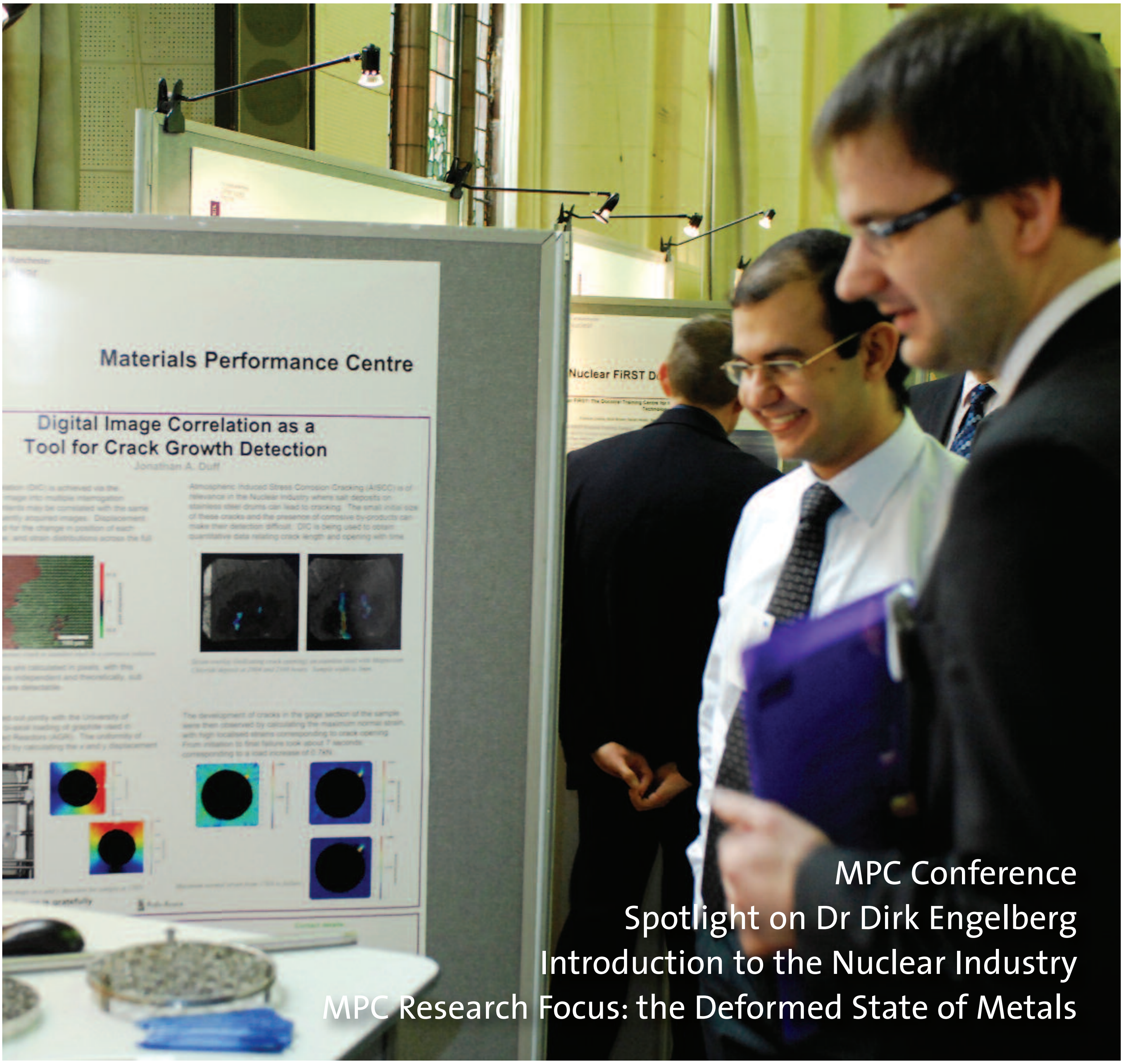
MPC NEWSLETTER

Issue 11 - Summer 2010

The Newsletter of The Materials Performance Centre



MPC Conference

Spotlight on Dr Dirk Engelberg

Introduction to the Nuclear Industry

MPC Research Focus: the Deformed State of Metals

National Nuclear Laboratory

EDF

British Energy
PART OF EDF ENERGY

serco

THE DIRECTOR'S CUT

Welcome to the latest issue of the MPC Newsletter, which provides news and research updates on the Materials Performance Centre (MPC) at the University of Manchester and looks forward to future developments.

Our cover image was taken at the launch of the new Rolls-Royce University Technology Centre at the University of Manchester, on 5th May. The UTC, dedicated to nuclear technology, will focus on material properties, modelling of processes in the nuclear plant as well as safety and reliability, with applications in both civil nuclear power and marine propulsion. The MPC has research strengths across these areas, and so will play a vital part in the UTC, which was established to offer high-quality technology for Rolls-Royce and real-world challenges for the academic partners. Colin Smith, Rolls-Royce Director of Engineering and Technology, commented that: "We take great pride in selecting universities that are world leaders in their field. We are delighted that these new UTC collaborations [one with Manchester and one with Imperial] will help us remain at the cutting edge of technology." Professor Tim Abram, Professor in Nuclear Fuel technology, will head up Manchester's UTC, supported by Michael Preuss from the MPC.

This issue's centre feature showcases two of the winning posters from the MPC conference, which was held in January. The MPC conference marked the start of a busy year of events at the MPC. So far we have hosted the Annual British Energy Graphite Meeting (for the fourth year in a row), Westinghouse's two-day Materials Centre of Excellence 2010 Zirconium Workshop, and a 3-day meeting of the European Commission FP7 PERFORM 60 project. The MPC also played a major role in organising the RR-UTC launch event. We value opportunities to host such events as a way of maintaining good relationships with our partners in industry and academia, facilitating their work and enhancing our own research connections. If you are hosting a future event that you think we may be able to assist with, please email mpc@manchester.ac.uk.

In February colleagues from the National Nuclear Laboratory came to the MPC to provide training on the nuclear industry for the newer MPC researchers. The day was a great success, as well as a useful learning experience. You can read more about it on Page 3. We're committed to hosting and providing such training, so please look out for details of future events that may be of benefit to you. Feel free also to suggest possible areas for training collaboration.

Our "Spotlight On…" feature this issue is about Dr Dirk Engelberg. Dirk has been with the MPC since its beginnings. At the end of March, Dirk took up a new post as BNFL Lecturer in Materials Performance / Geological Disposal at the University of Manchester's new Research Centre for Radwaste Disposal (RCRD). Although we are sad to be 'losing' Dirk, we look forward to maintaining a close working relationship with him in his new post. Many congratulations to Dirk!

Our congratulations go also to Kerry Taylor-Kousoulou and Anthony Horn, who have successfully passed their PhD vivas since our last newsletter. Well done!

Enjoy this issue of MPC News. We always welcome comment and feedback.

I'm sad to say that this will be my last newsletter, as I'm leaving Manchester this summer to take up the James Martin 21st Century School Chair in Energy Materials at Oxford University. However, Manchester and Oxford have built very strong collaborations in recent years, and I'll be maintaining close contact with the MPC through several projects. Working with the MPC has been a great experience, and I wish the MPC and the interim Director, Michael Preuss, every success with the great opportunities that lie ahead.

Dr James Marrow
Director, Materials Performance Centre

TED SMITH

Prof. Edwin (Ted) Smith passed away peacefully on Sunday 4 July following a short illness. Ted was a major influence at the University of Manchester since 1968 when he joined as Professor of Metallurgy following seven years at the Central Electricity Generating Board. His vision, combined with that of his counterpart at UMIST, Prof. Ken Entwistle, led to the creation of a joint Metallurgy Department in the 1970s. He was Dean of Science (1983-85), Pro-Vice-Chancellor (1985-88), and thereafter Emeritus Professor and Consultant. He was elected as a Fellow of the Royal Society in March 1996 for his pioneering work on brittle fracture. He was particularly proud of his work on delayed hydride cracking undertaken in collaboration with Dr. Doug Scarth of Kinetrics, Canada, over the last 20 years. He was a marathon runner and had a great love of all sports. He was a major influence on friends and colleagues in both academia and industry and will be greatly missed by all. We send our sincere condolences to his family and close friends.

MPC DIRECTORSHIP

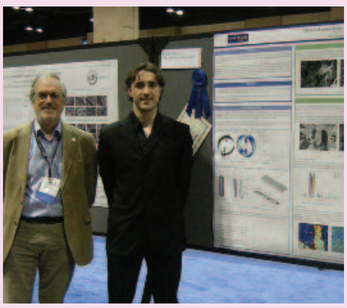
We are delighted to announce that Michael Preuss has agreed to provide interim leadership of the Materials Performance Centre (MPC) following James Marrow's appointment to the James Martin 21st Century School Chair in Energy Materials at Oxford, and while we appoint James' successor.

Michael will ensure that the MPC remains focused on the leading research in nuclear materials performance, that its industrial partnerships continue to grow and will be exploring new grant opportunities with EPSRC.

We can also announce that Michael has just been awarded a prestigious EPSRC leadership fellowship to work on irradiation damage in zirconium cladding material.

We are extremely grateful to James for his leadership of the MPC, during which time the MPC has continued to flourish in establishing new research programmes, graduate PhD students and publish widely. We wish him every success in the future and look forward to continued collaboration with him and his colleagues at Oxford in future years.

CORROSION AWARD



We are very pleased to report that EDF-sponsored MPC PhD student Fabien Leonard won the first prize in the Mars G Fontana (Corrosion Engineering) category at this year's NACE International's Corrosion conference for his poster "SCC of Alloy 600 in Primary Water Environment". The conference took place in San Antonio, Texas, in March. Many congratulations, Fabien!

INTRODUCTION TO THE NUCLEAR INDUSTRY

As previewed in our last issue, on February 8th Walter Weaver and Dave Goddard of the National Nuclear Laboratory came to the MPC to deliver a course entitled Introduction to the Nuclear Industry, which has also been held here in previous years. A maximum number of attendees were present on the day, comprising students, post-docs, staff and visitors from the MPC and the University of Manchester. The response to the day was overwhelmingly positive, reflected by a selection of the comments received in anonymous feedback:

- "Really useful introduction to the nuclear industry. Much appreciated!"
- "The presentations were an excellent way of showing the bigger picture of the way the nuclear industry operates."
- "Brought together a lot of info which otherwise would have taken me months to find and organise. Very worthwhile and interesting day."
- "An excellent introduction to the industry and the technical issues."

It is fully anticipated that the course will run again in the future. For information, please email mpc@manchester.ac.uk

National Nuclear Laboratory

NUCLEAR COMMUNITY

NAMRC

NUCLEAR AMRC
ADVANCED MANUFACTURING RESEARCH CENTRE

The Nuclear Advanced Manufacturing research Centre (Nuclear AMRC) is a collaboration between the Universities of Sheffield and Manchester and was formally launched by Lord Mandelson in Sheffield in December 2009. The initiative includes a £33 million grant from Government, Regional Development Agencies and the EU to build a new factory and training facility on the Advanced Manufacturing Park on the Sheffield/Rotherham border and to significantly expand The University of Manchester's nuclear research laboratories.

The Nuclear AMRC will be led by the University of Sheffield with Manchester leading on the research. Founding members include Corus/Tata Steel, Rolls-Royce, Westinghouse, Areva and Sheffield Forgemasters. Manufacturing supply chain engagement, training and accreditation will be focused in the new main facility. Manufacturing research innovation in the areas of materials, welding and surface technology alongside will take place in Manchester alongside the validation of new manufacturing technologies in nuclear environments. Full-scale R&D including welding and joining, assembly, machining and NDT up to prototype demonstration will take place within the Sheffield main site. Subsequent dissemination to the UK manufacturing supply chain will help members to become market leaders and suppliers to the new national and international new nuclear build programmes. www.namrc.co.uk

NEW APPOINTMENTS

The MPC looks forward to working with Professor John Yates, Professor Peter Storey and Dr. Andrey Jivkov, who are new members of the University of Manchester's nuclear team. Prof John Yates has been appointed the EDF Chair in Modelling and Simulation, based in the School of Mechanical Aero and Civil Engineering. Prof Peter Storey is Professor Nuclear Policy and Regulation and Director of Dalton Continual Professional Development Centre, aiming to establish a wide portfolio of new 'through-career' learning programmes at technical, managerial and executive levels. Dr Jivkov, an expert modeller, joins the recently formed Radwaste Disposal and Decommissioning Research Centre and will be based in MACE.

MPC CONFERENCE 2010

On January 18th the MPC held its first in-house conference. This one-day event comprised presentations by all key members of MPC staff, as well as two poster sessions showcasing current work by the MPC's PhD and post-doctoral researchers.

The intention for the day was to give all MPC members a chance to familiarise themselves with each other and their colleagues' work, particularly essential as the MPC moves closer to 100 members. It was also hoped that the day would enable researchers to see the broader context of their projects, establishing links between seemingly discrete areas, encouraging knowledge transfer and facilitating collaborative working.

The feedback from attendees was very positive, and the day seems to have achieved its aims in the short term, as well as hopefully in the long-term. Several industry key colleagues attended the conference and were impressed, expressing their enthusiasm at the following day's MPC Steering Committee.

It is intended that this will become an annual event. It is envisioned that there will be a slightly different focus each year, incorporating and making best use of the unique expertise of industry partners and university technical staff. In this way, the MPC's researchers can benefit from a full and enriched programme throughout their time here.

Over the page, our centre spread features two of the winning postgraduate posters from the event (with the two winning PDRA posters to feature in our next issue). The posters (over 40 in total) were displayed during two sessions, one for work by PhD students and one for PDRAs. All conference attendees were asked to vote for their favourite two posters in each category. Vendel Szeremi took first prize in the PhD category, closely followed by Fabien Leonard in second place and Fabio Di Gioacchino in third. Joint winners in the post-doctoral researcher category were Dr. Alison Mark and Dr. Jonathan Duff.

MPC CONFERENCE 2010 - POSTGRADUATE POSTER WINN

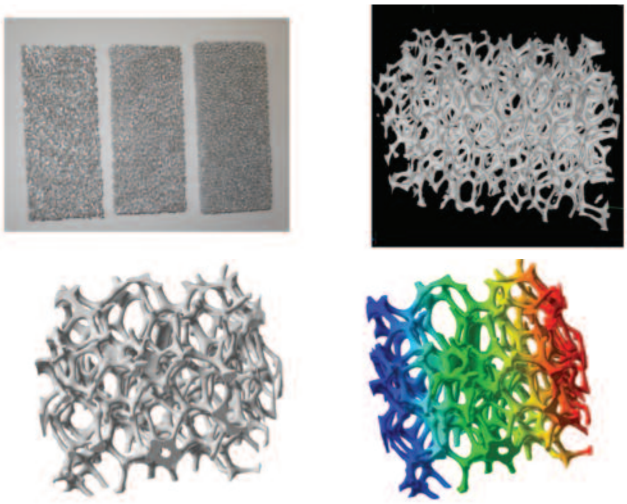
THERMAL AND THERMO-ELASTIC SIMULATION OF FOAM

V. Szeremi, P. Mummery, J. Santiago-Prowald (ESA)

Image-Based Modelling

Image-Based Modelling is used to simulate the thermal and thermo-elastic behaviour of foams. This simulation technique makes use of actual material microstructure acquired by X-ray microtomography (XMT) which is used to generate a Finite Element (FE) mesh. The bulk properties of the foams are then extracted from FE analyses.

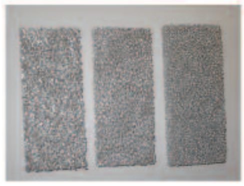
The three main steps in this approach are: 1) XMT scan 2) FE model generation 3) FE analysis and bulk property calculation.



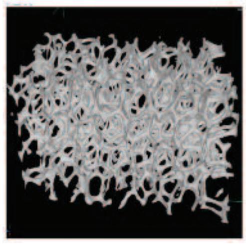
The different Image-Based Modelling steps: Specimen, XMT Scan, FE Mesh Generation, FE Simulation

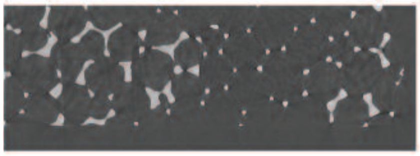
Foam Specimens and XMT Scanning

A number foam samples are examined in this project, including the open cell aluminium foam shown here. The foam specimens are scanned with the XTek devices in the Henry-Moseley Imaging Facility.



Top right: Selection of Aluminium foam samples
Bottom right: 3D reconstruction of XMT scan
Bottom: 2D Slice of XMT scan

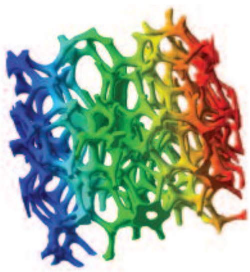




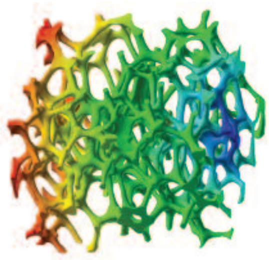
FE Simulation and Bulk Properties

FE Simulations using ParaFEM on a regular workstation and also on the Horace and Hector services to handle the large number of elements.

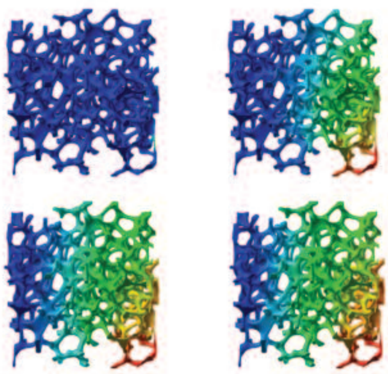
The simulations require properties of the constituent materials, aluminium in this case. From the FE analysis bulk properties of the aluminium foam are derived, including conductivity, specific heat, diffusivity, coefficient of thermal expansion.



Steady State Thermal Transport Simulation (temperature)



Thermo-elastic Simulation (magnitude of displacement)



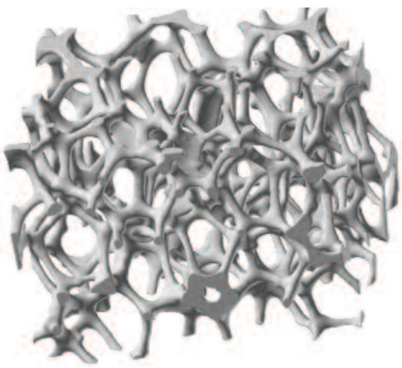
Transient Thermal Transport Simulation (temperature)

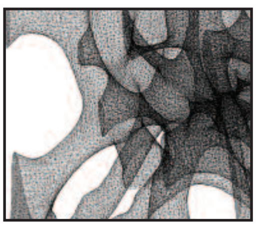
Foam FE Models

FE Models are generated from the XMT data with the Simpleware software packages ScanIP and ScanFE. They allow the creation of smooth tetrahedral meshes.

The meshes need to accurately reflect the topology and volume fraction of the sample. Using different volumes also affects the simulation results as the foams are inhomogeneous. Therefore a representative volume must be found and used.

*Right: FE Model of Aluminium Foam with 1,048,152 nodes 4,497,981 elements 13.53mm * 9.20mm * 13.53 mm*
Bottom: Close up of FE Model





SCC CRACKS IN NUCLEAR POWER PLANTS

Fabien Léonard, Robert Cottis and Francois Vaillant

Context

Stress corrosion cracking (SCC) of alloy 600 is regarded as one of the most important challenges to nuclear power plant operation as most nickel-based alloys employed in pressurised water reactors are subjected to SCC.

The objective of this project is to obtain a better understanding of the effects of the manufacturing process (forged vs. rolled) and of the various metallurgical parameters (microstructure, grain size, strain path...) on alloy 600 SCC susceptibility to improve the engineering Index Model used for component life assessment.

Experimental Results

Two heats of alloy 600 representative from plant components (CRDM nozzle WF675 and divider plate 78456/337) are under investigation, the microstructures are presented in Fig 1.

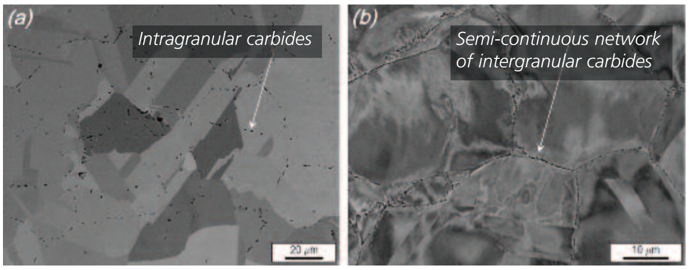


Fig 1. Microstructure of (a) WF675 and (b) 78456/337

Materials have been tested in primary water at 360 °C (2 ppm Li, 1000 ppm B, and 25 cc/kg H2) for 5000 hours using a custom-designed set-up called proving-ring (Fig. 2).

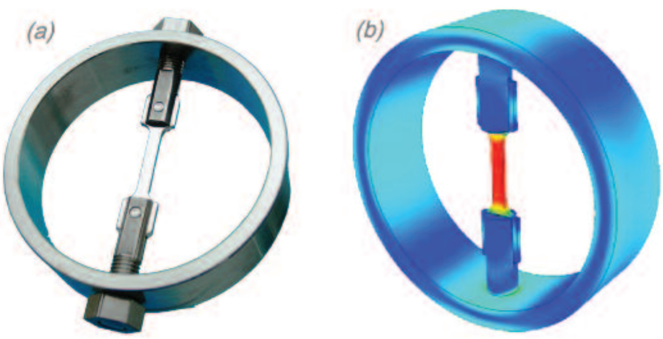


Fig 2. Picture of (a) proving ring and (b) corresponding modelling

During SCC testing, WF675 specimen (Fig. 3a) failed after 1440 hours under 671 MPa whereas 78456/337 specimen (Fig. 3b) did not reveal any significant stress corrosion cracking.

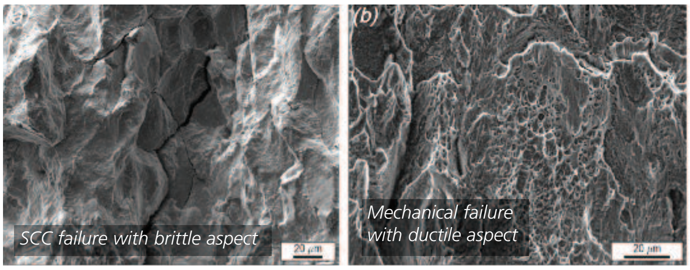


Fig 3. Fracture surface of (a) WF675 and (b)78456/337

Crack depth on non-failed WF675 specimens has been assessed as a function of the specimen orientation (Fig. 4 and Fig. 5).

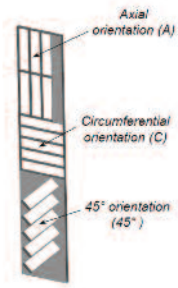


Fig 4. Sample orientation

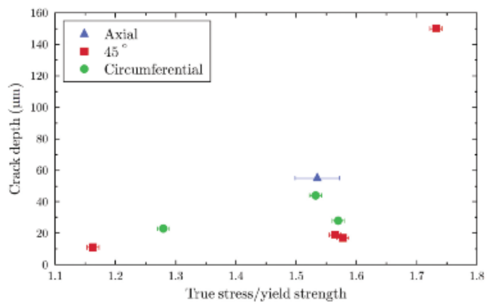


Fig 5. Damage assessment of non-failed specimens

Conclusion

The manufacturing process (forged vs. rolled) has a direct influence on the material microstructure and therefore a dramatic effect on the stress corrosion cracking behaviour.

A set-up called proving-ring has been successfully modelled and used in high temperature high pressure water as a simple, compact, accurate, and easily-operated device for applying axial loads.

SCC testing demonstrated that the most susceptible orientation was the axial orientation and the least susceptible the 45° orientation, future work will link these results to the strain path parameter [1] in order to implement the Index Model.

[1] F. Léonard, R.A. Cottis, F. Vaillant, et al., Mechanistic studies of stress corrosion cracking of nickel-base alloys in high temperature high pressure water PWR environment, 14th Conference on Environmental Degradation, Virginia Beach, Virginia, 2009.

The financial support of Electricité de France and EPRI through the Materials Performance Centre is gratefully acknowledged.

ENCOURAGING FUTURE SCIENTISTS

Robert using our Raman Microscope

Hello my name is Robert Jefferies, a pupil at nearby Priestnall School, and I have just done my work experience in the Materials Performance Centre at The University of Manchester I had a great time there and worked with many different people who all made me feel very welcome. Here is a summary of some of the things I did during my work experience.

I learnt how to test a metal sample in a Vibraphore fatigue machine. A Vibraphore simulates high cycle fatigue and suggests the amount of time a sample will take to break under a given amount of pressure

I also learnt about the composition type of corrosion/pitting and how to compare the different effect of this between stainless steel to iron. I tested the resistance to pitting of a metal using an electrode to simulate a pitt and used polarisation curves to interpret the data.

I was taught how to prepare metal by grinding, polishing and etching a sample to prepare it for examination it under a microscope. This allows you to see the grain of the metal and where its faults are.

On top of all of this I have learnt some key skills for university. I am sure to remember this for a long time. Thank you

Robert Jefferies is a pupil from Priestnall School. He spent a week's fully-supervised work experience at the MPC in March this year. We have had at least one work experience student here for the past several years, and hope to continue this practice.

SPOTLIGHT ON... DR DIRK ENGELBERG

Dr Dirk Lars Engelberg is the BNFL Lecturer in Materials Performance / Geological Disposal at the new Research Centre for Radwaste Disposal (RCRD) at The University of Manchester.

Background & Awards

Dr Engelberg started his career in Germany with a 3-year vocational training as an Electroplater. After a successful completion in 1994, he then worked for a short while in the chemical process industry, before he moved to the department of Surface Engineering and Materials Science at the University of Aalen, Germany.

Dr Engelberg first became involved in corrosion research during a 6-month internship in Wellington, New Zealand (Materials Performance Technologies), where he investigated the corrosion behaviour of materials in volcanic environments. Back in Germany he then completed his degree at the University of Aalen in 2000, and afterwards joined the Corrosion and Protection Centre, UMIST. After a successful year in Manchester, Dr Engelberg completed his MSc in Corrosion Science and Engineering in 2001. He then moved on to a PhD with Dr James Marrow and Prof Roger Newman on "Grain Boundary Engineering for Intergranular Stress Corrosion Resistance in Austenitic Stainless Steel".

In 2000, Dr Engelberg received the Best Graduate Award from the department of surface engineering and materials science at the University of Aalen, Germany, and in 2007 he was awarded the Armourers and Brasiers' Company Fellowship Award for Excellence in Materials Science and Technology.

MPC Involvement & Research Interests

In 2005, Dr Engelberg joined the MPC corrosion team as a Post-Doctoral Research Associate. With his background in metallurgy and corrosion, Dr Engelberg's research has mainly been concerned with localized corrosion and stress corrosion cracking of stainless steels and nickel-base alloys for nuclear application. He also developed a keen interest in the application of novel process routes for microstructure engineering, and the effect of process history on corrosion behaviours. Most of his research was funded by, among others, Rolls-Royce Marine and EDF.

Working at the forefront of in-situ characterisation, Dr Engelberg has also been deeply involved in the application of X-ray computed tomography for the in-situ study of localised corrosion. During his research he achieved the first in-situ 3-D X-ray tomography observations of intergranular stress corrosion cracking in sensitised austenitic stainless steel. These observations now form the basis of a meso-scale crack propagation model to improve stress corrosion cracking resistance.

Currently, Dr Engelberg also investigates a broad variety of corrosion-related imaging projects, using the new X-ray tomography facilities at the Henry-Moseley X-ray Imaging Centre at the University of Manchester. Most of his current research is carried out with Prof. Philip Withers and Dr James Marrow.

Dr Engelberg has authored comprehensive reviews about Stress Corrosion Cracking of Inconel 718 in PWR Environments and Carbide Precipitation with Relevance to Low-temperature Crack Propagation in Alloy 82 Weld Metal. He also wrote the chapter about intergranular corrosion for Shreir's Corrosion.

Future / Research Centre for Rad-waste Disposal (RCRD)

In his new position as a Lecturer in Geological Disposal, Dr Engelberg will continue his research on localised corrosion and stress corrosion cracking of steels and stainless steels. With a wide range of experts from materials, corrosion, radio-chemistry, geology and biology involved in this new research centre, Dr Engelberg also plans to build upon this broad expertise with joint projects relevant to nuclear waste storage conditions. Typical projects include, for example, microbiologically-induced corrosion (MIC), corrosion of steels/stainless steels in clays and cementicious environments, or the decontamination of stainless steel components prior to decommissioning.

Away from the MPC

In his spare time Dr Engelberg either chases his wife and 2 year old son around playgrounds, is heavily involved with DIY-based projects, or tries to keep fit with "jogging-expeditions" through nearby parks and woodlands.

NUCLEAR METALS RESEARCH: THE DEFORMED STATE

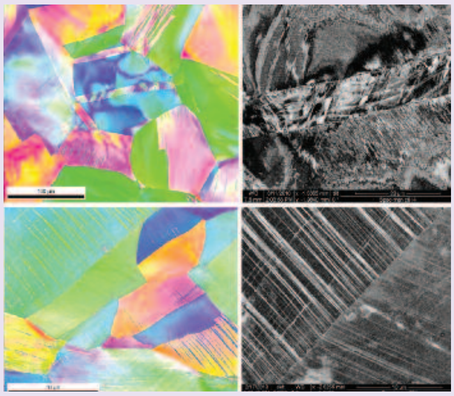
Understanding the deformed state of metals is highly relevant to all aspects of nuclear metal component performance from fabrication through to decommissioning. It is therefore unsurprising that the deformed state of metals is a thriving area of research in the Materials Performance Centre, with 10 PhD students whose projects either focus entirely on it or depend heavily on understanding it. It is not an easy topic. Understanding the deformed state of metals involves reconciliation of the discrete generation, movement and rearrangement of dislocations and other defects at the atomic scale firstly with the patterns of deformation at the microstructural scale and ultimately with the smoothly varying stress and strain fields of continuum mechanics which is the basis the engineering models at the component scale.

Although diffraction peak profile analysis has long been used to quantify parameters like dislocation density and grain size, these methods have often showed a lack of agreement with transmission microscopy studies. This has led to a lack of interest in developing despite their great potential. In his EPSRC funded project, Thomas Simm has been looking at how diffraction techniques can be used to characterise the deformed state. He has used crystal plasticity modelling to understand these assumptions and propose useful guidelines for interpreting the results of these different methods. His findings will certainly contribute to the development of future crystal plasticity models but will also provide a framework that will be useful for bulk characterisation of irradiation damage in metals.

The effect of cold work on stress corrosion cracking (SCC) is a good example of how the deformed state can affect performance in service. It has been found that even alloys like Inconel 600, which should be immune to SCC in typical plant environment, do crack when they are cold worked. This is the topic of an ongoing collaboration research project with EdF, where the effects of fabrication route, annealing and amount of cold work and on SCC susceptibility are being studied systematically. Nina Lohro is the PhD student on this project, whose work makes full use of characterisation capabilities including electron backscatter diffraction (EBSD) at Manchester and the extensive SCC testing facilities at EdF.

The effect of cold work on SCC is also the topic of another research project at the MPC in collaboration with Serco Assurance. Fabio di Gioacchino and David Wright are the postgraduate students studying the cold worked state of stainless steel. Together, they are combining advanced EBSD analysis of the deformed structure with high resolution SEM imaging both in-situ and post-mortem. Their work is making it possible to actually quantify the amount of deformation and heterogeneity at microstructural scale where it is relevant to SCC. The aim is to use this information alongside modelling of deformation at the grain scale to help predict susceptibility in different microstructures.

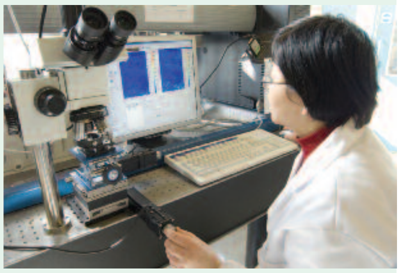
Studying the deformed state is also an important part of understanding how to fabricate nuclear components. Zirconium fuel elements, for example, are manufactured via a complex, multistage process which has been refined empirically over the years. Although the process works well, a lack of fundamental understanding of the physical mechanisms operating during processing makes it inflexible and difficult to scale. This is why the deformation of Zirconium alloys is an important topic of research at the MPC. Leo Prakash is our most experienced researcher in this area, working alongside Peter Honnibal and Chatri Booncharoen who are partly funded by Rolls-Royce and Westinghouse. Their work involves a wide spectrum of characterisation techniques, from neutron and synchrotron diffraction to EBSD, supported by crystal plasticity finite element modelling. It has already shown that twinning plays a surprisingly important role in the deformation of these alloys even at elevated temperatures.



EBSD maps and channelling contrast images of cold worked stainless steel. The distortions in the lattice are caused by fairly homogenous plastic deformation, on which highly localized features like slip bands and twins develop.

These are just a few projects in the MPC studying the deformed state of metals. Despite the inherent complexity, or perhaps because of it, it is a fascinating field of study. It is intensely rewarding from a scientific point of view and essential to understanding the performance of structural components in a nuclear power plant at all stages of life.

MPC EQUIPMENT CAPABILITIES



The MPC has since its inception been committed to the obtainment and upgrade of high-specification equipment for use within the centre and by the School of Materials. The main image here features two of our more recent pieces of kit (operated here by Dr Jonathan Duff), an InVia Raman Microscope and our Imaging Autoclave. The autoclave has been recently upgraded to allow electrochemical measurements (such as electrochemical noise) to be taken at the same time as stress corrosion crack initiation is studied by digital image correlation. This, together with the commissioning of our multi-dimensional imaging suite (smaller picture – operated by MPC visiting researcher Dr. Zhiuhua Zhu) and final installation of our Gleeble, has considerably enhanced the MPC's research capability in nuclear materials. The Gleeble allows complex thermal and strain cycles, such as those in welds, to be reproduced in bulk samples. This significantly aids study of weld microstructure properties and characterisation. The imaging suite is very critical in long-term studies of atmospheric stress corrosion initiation in stainless steels.

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