

Report

**NPL REPORT
DEPC-MPE 042**

Miniaturised Testing

**B Roebuck, L Brown,
J Banks, R Brooks, M Evans***

* IRC in Computer Aided Engineering,
University of Wales, Swansea

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Miniaturised Testing

B Roebuck⁺, L Brown⁺, J Banks⁺,
R Brooks⁺, M Evans*

⁺Engineering and Process Control Division
National Physical Laboratory, Teddington, TW11 0LW, UK

* IRC in Computer Aided Engineering,
University of Wales, Swansea

ABSTRACT

This report summarises outcomes of a three year collaborative project on miniaturised testing between the Materials Centre at NPL and the IRC in Computer Aided Engineering at the University of Wales, Swansea. It also notes comments and remarks at an Interest Group meeting at NPL on 28 March 2007.

The collaborative project produced a numerical model of the small punch (SP) disc test and used this model to determine optimum testpiece and jig dimensions to maximise the sensitivity of the test. SP tests were conducted to validate the model. Uniaxial tests were undertaken in parallel with the SP tests, particularly on a thermally exposed $\frac{1}{2}\text{Cr}\frac{1}{2}\text{Mo}\frac{1}{4}\text{V}$ steel, which demonstrated the ability of miniature testpieces to generate data that discriminated well between different material types. However, oxidation tests in the uniaxial test rig indicated that it would be sensible to conduct long term SP tests on Fe alloy samples in inert environments.

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National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

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Approved on behalf of the Managing Director, NPL,
by Dr M G Gee, Knowledge Leader, Materials Performance Team
authorised by Director, Engineering and Process Control Division

CONTENTS

1	INTRODUCTION.....	1
2	MATERIALS	2
3	MODELLING	2
4	SMALL PUNCH TESTS.....	6
5	MINIATURE UNIAXIAL TESTS	8
6	EUROPEAN LINKS.....	13
7	FORWARD LOOK	14
8	ACKNOWLEDGEMENTS	15
	APPENDIX A	16
	APPENDIX B	20

1 INTRODUCTION

This summary report provides notes on discussion and issues raised at a special Interest Group Meeting (IG) held at NPL on 28 March 2007 to discuss a project in the DTI Materials Performance Programme on Miniaturised Testing, as well as a summary of a collaborative project, on miniaturised testing conducted in partnership between NPL and the IRC in Computer Aided Engineering at the University of Wales, Swansea. A list of contact details of members of the IG are given in Appendix A. The project rationale and objectives are included as Appendix B. The project ran from April 2004 – March 2007 and this interest group meeting marked the end of the project. Follow-up projects are being gauged through a questionnaire to Interest Group members.

Presentations

Project issues were addressed in three formal presentations. These are to be circulated to the IG members and contacts on a complementary CD. They included

Introduction	B Roebuck	NPL
Modelling	M Evans	IRC
Mechanical Testing	B Roebuck	NPL

In addition a range of presentations were made at the IG meeting by external attendees on contingent topics, including

Miniature Testing Requirements at Corus	P Morris	Corus
Microstructural Characterisation Techniques	R Thompson	Loughborough University
Impression Creep Testing	W Sun	University of Nottingham
SP Standardisation	R Hurst	JRC, Petten
Impression Creep – ½CrMoV Pipework	S Brett	RWEnpower

These presentations are also included on the complementary CD.

Background

For plant and structures operating at elevated temperatures for long times degradation processes impair mechanical properties, especially the creep resistance of their components. Requirements for environmental sustainability make it economically convenient to extend the lifetime of existing components rather than build new plants. Thus, reducing uncertainty in the calculation of the remnant life of plant is critical. Components or structures are designed with significant safety margins but these can be reduced throughout a service life by ageing, i.e. the mechanical characteristics of structural materials change with time or use. An understanding of the change in mechanical properties of structural components with ageing is thus necessary for optimising operating procedures, inspection intervals, repair strategies and lifetime assessments.

Optimising the test conditions for relevant miniature tests is an important objective together with correlating the results with those from full size samples. A suitable numerical model of the disc test with protocols and good testing practice for relevant tests is also being developed. The testing technique is limited by the fact that an agreed standard procedure for

such tests does not exist, and this being addressed through a CEN Working Agreement, (see Section 6), which provides detailed information on material procurement and testing procedures.

2 MATERIALS

Miniaturised tests (both SP and uniaxial) for the DTI funded project were conducted on P11 steel (1 Cr $\frac{1}{2}$ Mo), supplied by the IRC, Swansea and P12 steel ($\frac{1}{2}$ Cr $\frac{1}{2}$ Mo $\frac{1}{4}$ V) supplied by E.ON. The P11 steel had been evaluated in the as-received (heat treated normalised and tempered) and one exposed condition (300 h, 580 °C, 135 MPa). The time to failure under these conditions was 536 h. The P11 was taken from a thick wall seamless pipe. The P12 steel was supplied by E.ON after 198 and 240 kh exposure.

3 MODELLING

The primary objectives of the modelling part of the project were; to optimise test conditions for SP disc tests, to correlate results with macroscopic uniaxial tests, and to develop good testing practice. A FE computer simulation of the disc test had been demonstrated at previous IG meetings. Friction and prior damage were shown to be very important in influencing the shape of load displacement curves. It was noted that a greater scatter in ductility compared with scatter in rupture life was observed in experimental SP tests. One of the key objectives of the modelling exercise has been to investigate the sensitivities to damage (maximise) and geometry (minimise). Figure 1 illustrates some of the results that quantify these sensitivities.

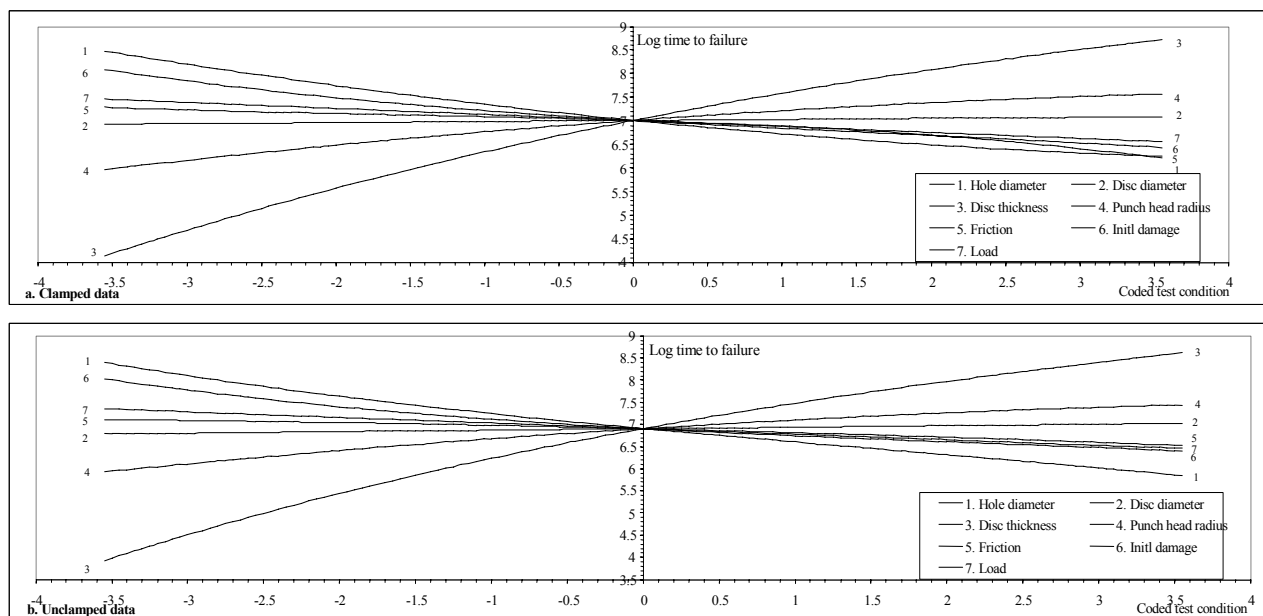


Fig 1 Sensitivities to test parameters for (top) clamped data and (bottom) unclamped data.

Much of the modelling work has or is about to be published and details follow below:

1. R W Evans and M Evans; Numerical Modelling the Small Disk Creep Test; *Journal of Materials Science and Technology*, 2006, 22, No 10, pp 1155-1162.
2. M Evans and D Wang; Optimising the sensitivity of the small punch test to damage and test conditions; *Journal of Strain Analysis for Engineering Design*, accepted for publication (July 2007).
3. M Evans and D Wang; Stochastic modelling of the small disc creep test; *Journal of Materials Science and Technology*, accepted for publication – 2007.
4. R W Evans and G C Stratford; Modelling the Small Punch Creep test; Power Plant, Operation, Maintenance and Materials issues, 2007 4(1).
5. R W Evans and G C Stratford; Modelling the Small Punch Creep test; Proc Creep and Fracture in High Temperature Components; ECCC Conference, eds Shibli, Holdsworth and Merking, London.

Measurements of minimum displacement rate (MDR) from the SP test, when plotted against time to failure (t_f), frequently show the same type of dependency of t_f on applied stress as observed in uniaxial creep tests, but with a shift along the t_f axis. This shift is different for different materials, and different test geometries. An important objective of the project was to develop a better understanding of this shift, its dependence on test parameters and whether it is always parallel in nature. A comparison (Fig 2) of early experimental data on minimum displacement rate (from SP tests) and minimum creep rates (from uniaxial tests) had shown that they do not always sit on parallel lines. As other studies have shown parallel behaviour it implies that it may be difficult to convert SP data to uniaxial data using simple analytical expressions. It is debateable whether this similarity or not of shape of the $\dot{\epsilon}_{\min}$ v stress plot is an intrinsic property of the SP tests or is due to an expected scatter in creep test results. Consequently, in recent work the modelling study considered the effects of randomly (Monte Carlo) selecting data from variances observed in original creep data.

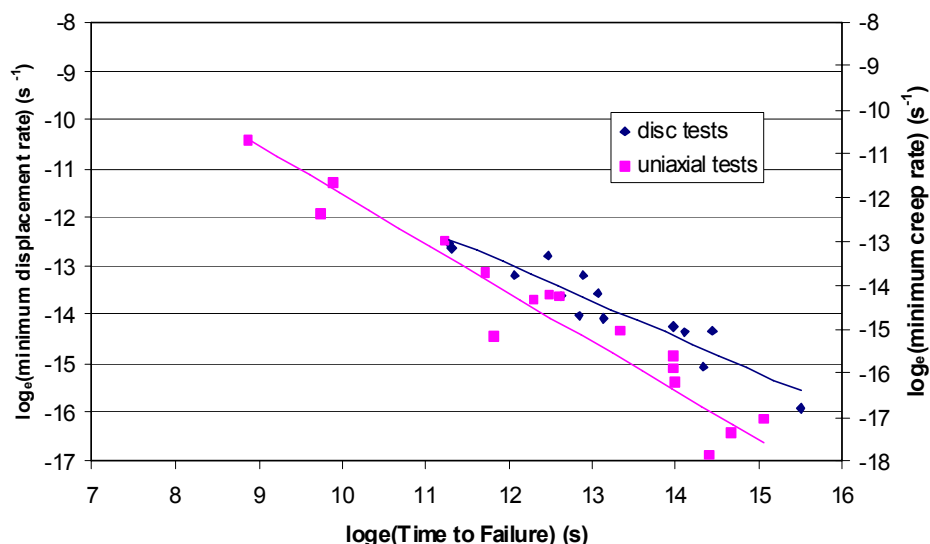
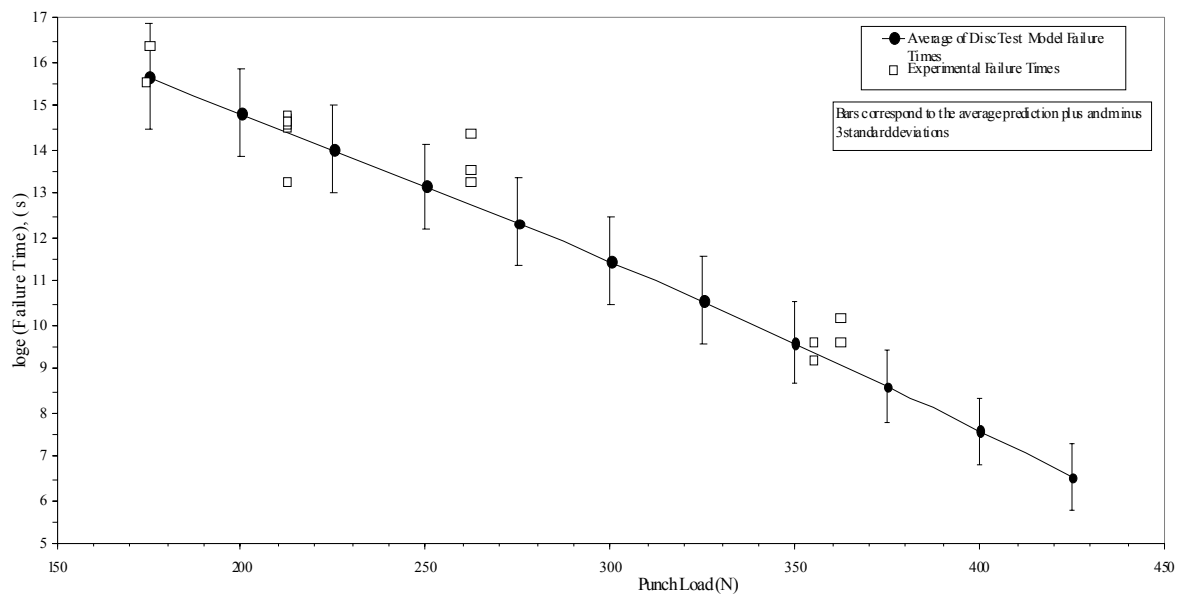


Fig 2 Comparison of experimental minimum creep rates from uniaxial tests with minimum displacement rates from SP tests.

Two versions of the model have been developed. The first was a deterministic model that does not take into account the variability observed in the multiaxial creep test data for P12 steel. The second version builds this variability into the small disc test so that confidence intervals for the models predictions are also obtainable. A Monkman – Grant type relation was found that was the same irrespective of the load and irrespective of the amount of pre existing damage that the discs contained. This relation varied slightly with disc thickness and punch head radius. For the load range 425N to 175N the load dependence of time to fracture predicted by the model could be well described by the power law equation:

$$(7.742 \times 10^9) \text{Load}^{-0.037} \quad (1)$$

Experimental tests were carried out on virgin P12 at 848K and over a wide range of loads



Failure times from experimental tests together with the average modelled predictions at 848K

with a disc diameter of 9.0mm, disc thickness of 0.5mm, punch radius of 1.0mm and a punch hole radius of 4.0mm. The small disc test model was then used to predict failure times at these conditions using a friction factor of 0.35. It was found that the model predictions for the mean time to failure at each test condition were in broad agreement with the experimental data and that all the data appeared to be within the models 99% confidence intervals for its predictions (Fig 3). Similar tests on P11 materials are ongoing.

Fig 3 Failure times from model predictions and experiments

The stochastic model was therefore run 15 times for a disc diameter of 9 mm, disc thickness of 0.5 mm, punch radius of 1.0 mm and punch hole radius of 4.0 mm and for loads varying between 425N and 175N. The resulting 15 slope estimates of the Monkman – Grant type relation are shown in Fig 4, together with their average and the models prediction of the 95% confidence interval for this slope. Also shown is the slope estimated from the uniaxial experimental data together with its 95% interval. Having taken into account creep variability, the results from the stochastic computer model suggest that the slope of the Monkman-Grant type relation is the same in uniaxial as it is in small disc test data – as revealed by the overlapping intervals.

This parallel nature suggests that it might therefore be a straightforward matter to convert small disc test data to uniaxial data using the standard analytical expressions.

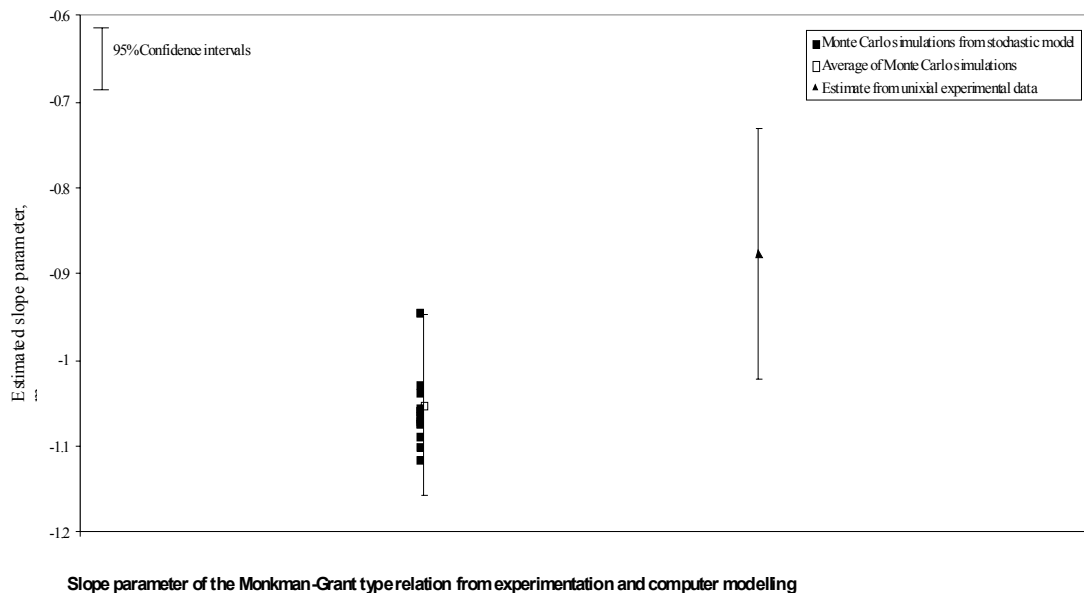


Fig 4 Comparison of slope parameters from model and experiments

A central composite design was selected to determine conditions under which the disc test model should be run to find optimum conditions. This amounted to 143 test runs under clamped and unclamped conditions. For each run the time at fracture and the minimum displacement rates were recorded. A polynomial model was then estimated from the failure times predicted by the deterministic model to approximate the response surface.

Under either clamped or unclamped conditions the log time to failure was found to be most sensitive to changes in disc thickness, hole diameter, pre-existing damage and the punch head radius and least sensitive to changes in disc diameter and load. It is therefore recommended that great care should be taken to ensure that disc thickness, hole diameter and punch head radius are consistently measured to the recommended specification. These specifications can be determined through the use of the partial derivatives with respect to associated failure times. The ideal outcome, i.e. the optimised condition, is one where the derivatives with respect to apparatus and specimen geometry are zero and where the derivative with respect to damage is maximised for any given load. At the optimum the test is most sensitive to pre existing damage and least sensitive to small variations in test geometry around these optimal levels. This will maximise the sensitivity of the disc test to the determination of remanent life.

The following conclusions were obtained under *clamped* conditions:

1. It was found that the optimum test geometry was the same irrespective of the load applied to the disc and the level of pre existing damage. This optimum test geometry, and hence the recommended best testing practice was found to be one that has a hole diameter = 8.66 mm, disc diameter = 8.01 mm, disc thickness = 0.64 mm and a punch head radius = 1.29mm. As friction was shown to have little effect on this optimal solution, issues related to lubrication during the test can be neglected.

2. Irrespective of the amount of pre-existing damage present in the test specimen or the load applied, the above test geometries will ensure that scatter in times to failure induced by small changes in these geometries will be 80% minimised.
3. However, the sensitivity of the test to pre-existing damage diminishes rapidly the more damage that is present. This sensitivity is maximised when there is no damage at all present. This sensitivity continually diminishes with the amount of pre existing damage until damage reaches 40% of the amount of damage at failure. Then sensitivity starts to increase towards the maximum recorded under no damage. For example, sensitivity falls to 55% of this maximum when damage is 15% of damage at failure and to 30% of this maximum when damage is 25% of damage at failure.

Under ***unclamped*** conditions the picture was less complicated:

1. It was found that the optimum test geometry was the same irrespective of the load applied to the disc and the level of pre existing damage. This optimum test geometry, and hence the recommended best testing practice was found to be one that has a hole diameter = 8.29 mm, disc diameter = 11.32 mm, disc thickness = 0.65 mm and a punch head radius = 1.07 mm. As friction was shown to have little effect on this optimal solution, issues related to lubrication during the test can be neglected.
2. Irrespective of the amount of pre-existing damage present in the test specimen or the load applied, the above test geometries will ensure that scatter in times to failure induced by small changes in these geometries will be 75% minimised.
3. Unlike with clamped conditions, the sensitivity of the test to pre-existing damage does not diminish at all with the amount of damage that is present. The sensitivity of times to failure to damage is maximised when the sensitivity to test geometries is minimised at the above test conditions and this sensitivity to damage remains the same at all levels of pre-existing damage present in the disc and at all loads that are applied to the disc.

It is therefore recommended from the modelling studies that the SP disc test should be carried out under unclamped conditions at the test geometries stated above.

This will ensure that the test is most sensitive to pre existing damage and least sensitive to small variations in test geometry around these optimal levels. This will maximise the sensitivity of the disc test to the determination of remanent life.

4 SMALL PUNCH TESTS

Standard procedures for mechanical tests usually require fairly large volumes of test material that can be taken from in-service equipment. This has led to the development of small punch (SP) test techniques based on penetration tests of miniature, disc-shaped, test specimens [1-4]. The SP test is a mechanical test carried out on a small disc-shaped testpiece by means of the application of a mechanical load applied to one surface of the test piece with a round-ended punch or ball in order to investigate its response to the applied force. In the NPL system the load is applied with a Si₃N₄ ceramic ball of radius 1.2mm and the disc is clamped with a thermocouple in the recess of the face of the clamp. In the IRC system the load is applied with a hemispherical-ended solid Nimonic rod of radius 1.0 mm and the temperature is measured with a remote thermocouple that had previously been calibrated with an instrumented testpiece. It is considered to be a non-destructive technique because of the small amount of testing material required to be sampled. It also enables the determination of mechanical properties of materials with spatial variation in structure such as welds. Discs are

usually machined to a thickness of approximately 0.55 mm and then ground on both sides to achieve a final thickness of 0.5 mm, with a tolerance of no more than $\pm 0.5\%$.

The disc diameters are generally $8 \text{ mm} \pm 1\%$. Heating systems are designed to provide a uniform temperature distribution throughout the test section of the disc. A temperature measuring system usually comprises thermocouples, located to determine that the testpiece remains within the temperature limits specified for the test. The temperature control system is generally capable of maintaining the temperature constant to within $\pm 0.25\%$ of absolute temperature, K, throughout the test.

Temperature measurement and distribution is important because of the difficulty in putting individual thermocouples on each testpiece. In developing good testing practice it is important to assess the magnitude of the uncertainty in temperature and what difference this makes to the mechanical data. A discussion of temperature control concluded that guidelines in current creep testing standards should apply equally to SP tests. For example, $\pm 3^\circ\text{C}$ on 600°C would be expected to result in about $\pm 25\%$ in minimum creep rate.

NPL SP tests had found that the results (lifetimes at given stress levels) were sensitive to aperture sizes within the range 3.8 to 4.1 mm (Fig 5). This agreed with the modelling studies where it was observed that aperture diameter was one of the most sensitive parameters. All the SP tests, both at Swansea and NPL had shown evidence of stretching prior to failure. Some longer term experiments are needed to check if failures were more creep brittle (expected from an increased propensity of cavitation at lower stresses). A similar exercise on testpiece thickness would also be helpful.

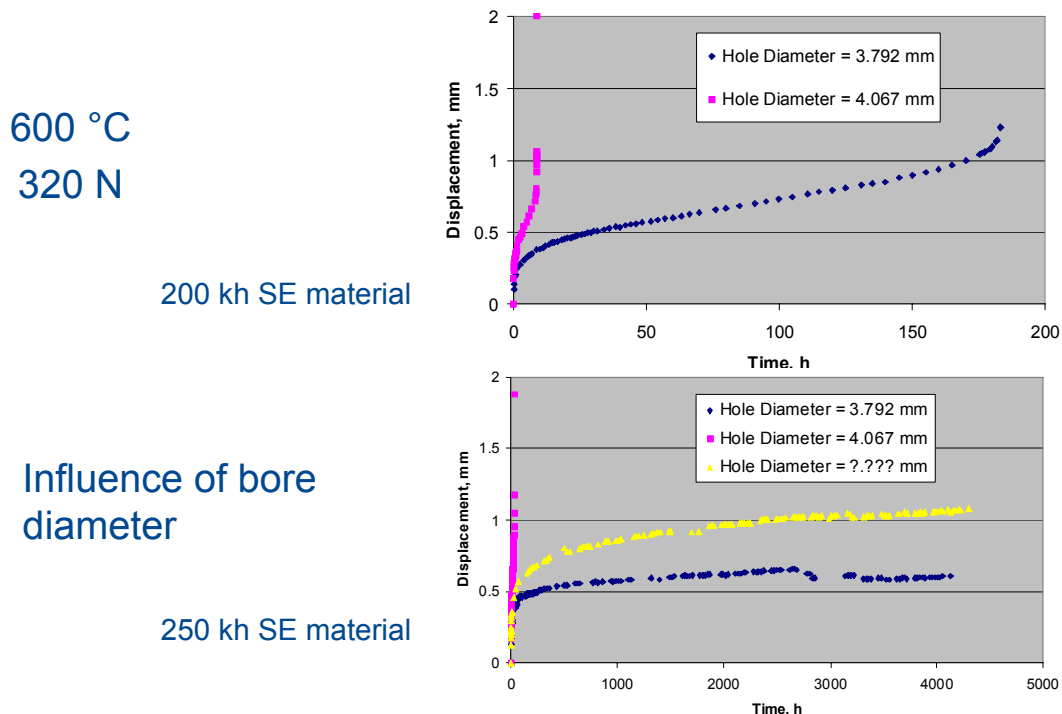


Fig 5 Influence of aperture diameter on SP creep test results.

Environment is clearly important for some materials. SP rigs generally have facilities to test in air or dynamic Argon. The NPL tests were not run in argon consequently there was considerable discussion of oxidation effects. It had been advised that, for the P12 steels,

testing should be at 620 °C maximum to ensure oxidation was not a problem. Consequently oxidation data were generated in tests in the uniaxial ETMT system to generate information on expected tolerances on dimensions (see below).

Effects of surface finish were discussed and it was concluded that if the damage was continuum based then failure times were not expected to be surface sensitive, and this had been supported in earlier experimental work at Swansea. It was agreed that observations of crack initiation sites and propagation directions would be helpful in validating the model predictions but that this might be difficult due to the problems of choosing the correct times at which to interrupt the test.

Stress multiaxiality was recognised as a possible issue. SP tests are initially biaxial, and then possibly multiaxial, as strain develops; whereas results with which the SP data is compared are often obtained from uniaxial tests.

5 MINIATURE UNIAXIAL TESTS

Good correlation had been found in measurements of strain using the resistance approach compared with macroscopic conventional strain measurements. The room temperature resistivities of the exposed materials were different to those observed in unexposed material and may indicate some correlation with damage. E.ON have sent NPL materials with known levels of cavitation damage for further examination by resistivity and mapping microhardness, but there was insufficient time in the project to conduct this investigation. Systematic and consistent data had been obtained from both tensile and constant load tests on the P12 and P11 steels but further tests were needed at lower stress levels to ensure correct deformation mechanisms were being observed. E.ON had provided data from tests on full sized test specimens. This data had compared well with the miniature uniaxial data from the ETMT (Fig 6), although it must be noted that in the current ETMT tests for times to fracture the tests were conducted under constant load (nominal stress) and not constant stress.

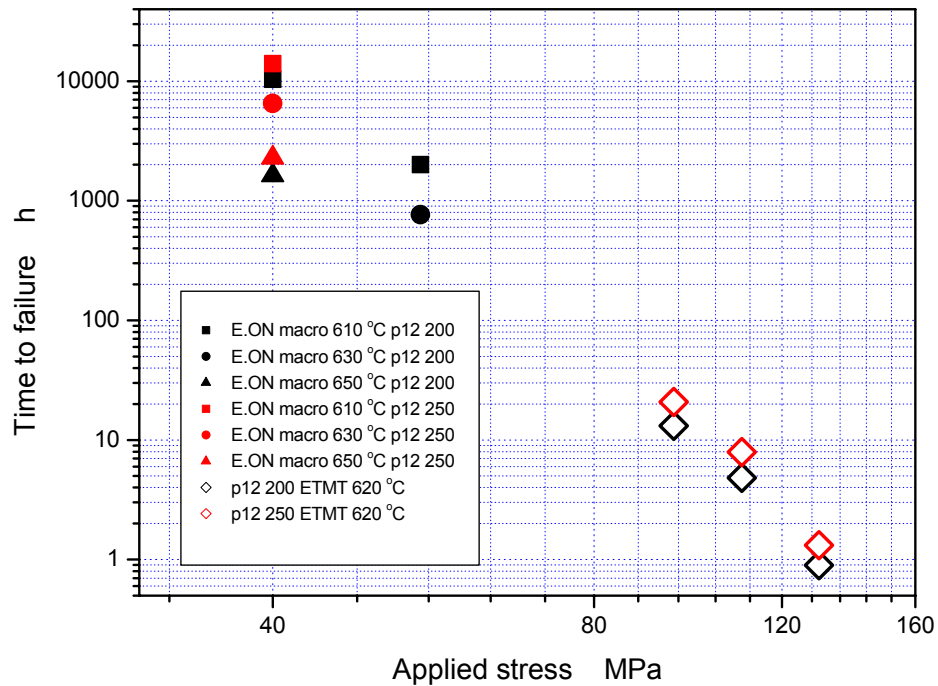


Fig 6 Comparison of macro and micro uniaxial data.

The ETMT tests have been carried out, for the most part, in an inert argon environment. However, some of the SP tests at NPL were at fairly high temperatures (≥ 600 °C) and for long times, when problems occurred with samples sticking to supporting rigs through excessive oxidation. Consequently, it was decided to use the ETMT to study oxidation kinetics, through measurements of changes in resistance, in order to provide guidelines for testing P11 and P12 in air in the SP tests.

For the ETMT tests simple rectangular cross section (2×1 mm) testpieces were heated, under zero load, to the test temperature of interest in argon to maintain clean surfaces. Then laboratory air was introduced and the oxidation process was followed through measurements of the change in resistance. As the sample oxidises the cross section decreases and the metal sample resistance increases.

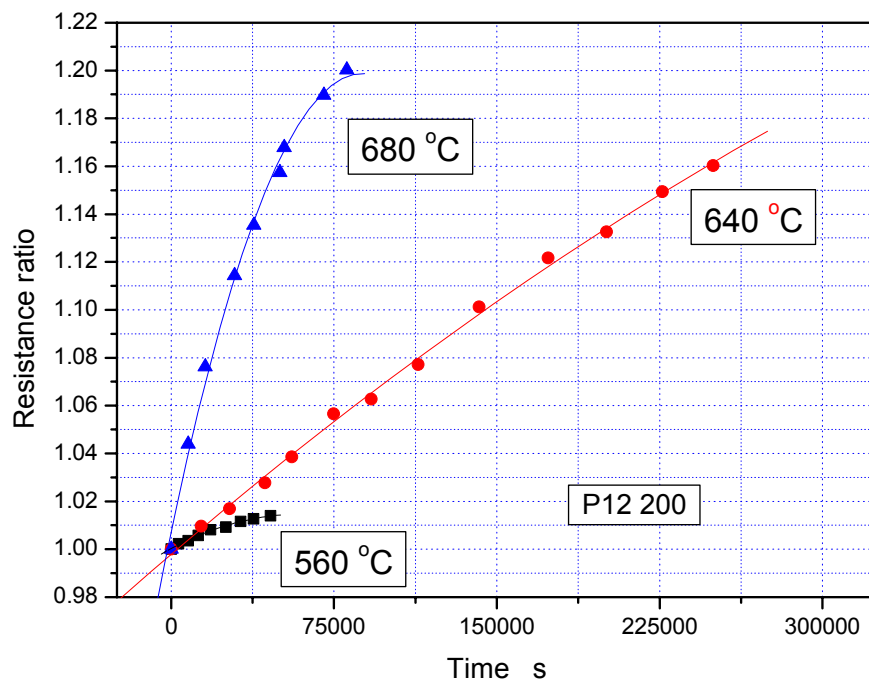


Fig 7 P12 normalised resistance changes in oxidation tests at various temperatures

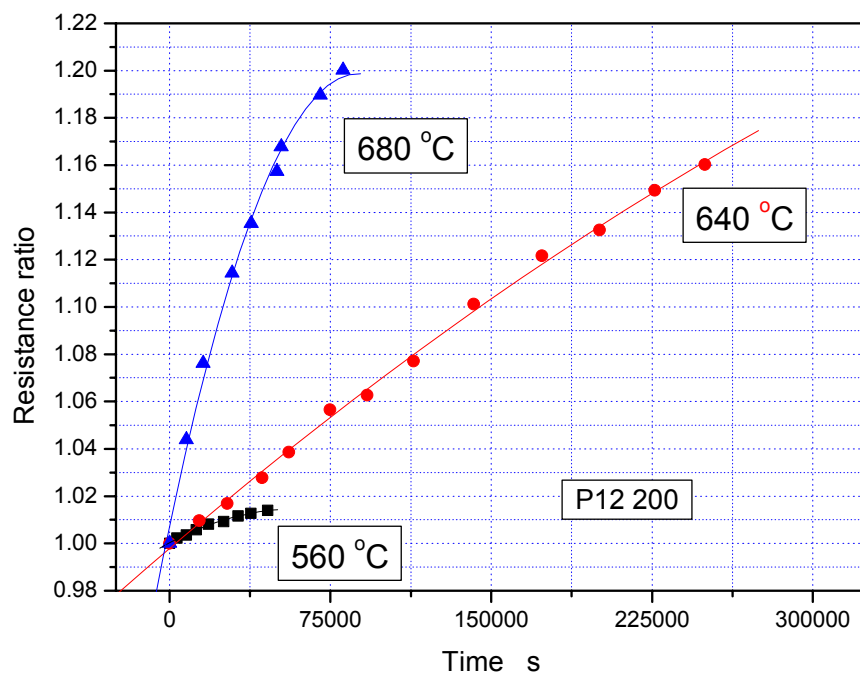


Fig 8 P11 normalised resistance changes in oxidation tests at various temperatures

Some measurements for tests between 560 °C and 680 °C on P11 and P12 are shown in Fig 7 and Fig 8 where resistance is plotted against time. The resistance values have been normalised to give a value of 1 at the starting point of the experiment. The changes in resistance can be used to derive (through simple geometrical assumptions) values for metal loss (in μm on each surface). These values are plotted in Figs 9 and 10 where the plots are expressed in logarithmic coordinates. It can be seen that the kinetics of oxidation are complex for these two materials over the chosen ranges of test temperature. The latter were selected to cover the range used for mechanical tests (i.e. between 550-700 °C). It appears that there is an initial slow oxidation process followed by an acceleration period to a new rate at longer times. This is consistent with a period where there is a relatively protective oxide layer followed by an accelerating growth process to a more open structure, associated perhaps with breakaway oxidation. The data in Fig 9 and Fig 10 show that both P11 and P12 oxidise at significantly high rates even at temperatures as low as 540 °C.

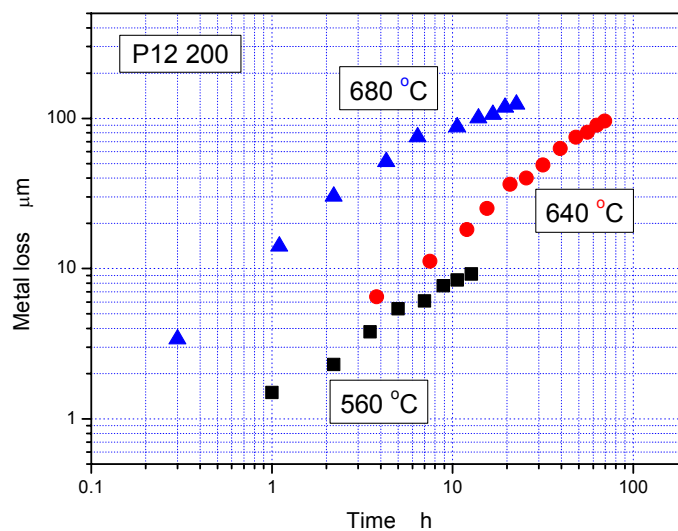


Fig 9 Metal loss kinetics in P12 steel at different temperatures.

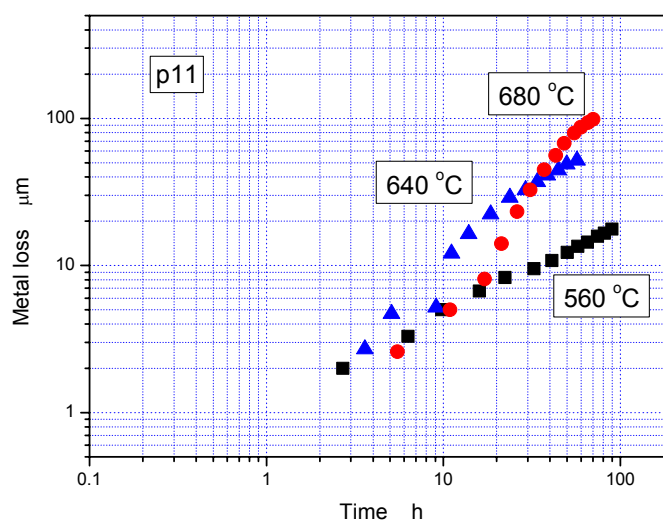


Fig 10 Metal loss kinetics in P11 steel at different temperatures.

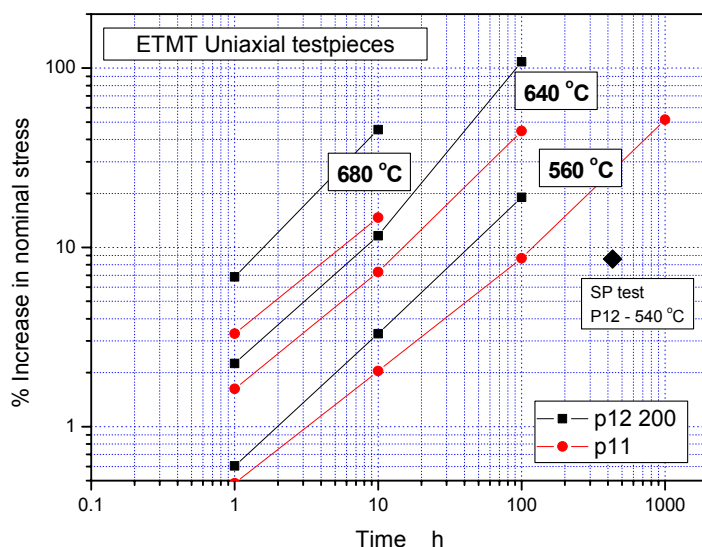


Fig 11 Effects of oxidation time on percentage changes in nominal applied stresses.

The metal loss kinetics can be converted to a graph (Fig 11) of nominal percentage stress changes plotted against time for a typical SP testpiece of original thickness 0.5 mm. If it is assumed that only a 5% change in stress can be tolerated then it can be seen that, even at temperatures as low as 560 °C, the loss in cross-sectional area becomes too great at times as short as 20h and 40h, for P12 and P11 respectively.

An additional data point is included in Fig 11 for a measurement of oxide thickness obtained from an interrupted SP test at 540 °C after 430h at 430 N. It is fully consistent with the ETMT uniaxial measurements and confirms the importance, in most cases, of planning miniaturised tests in inert atmospheres.

Some of the NPL work described above was disseminated through the following conference presentations and NPL reports:

I Mech E – Small Specimen Testing Seminar – May 22 2006

S Osgerby / R Evans – SP test and Models

B Roebuck et al – ETMT test system

B Roebuck and M Brooks; Uniaxial Tests using a Miniaturised Test Method; *NPL Report, DEPC MPE 030*, March 2006.

S Osgerby and J P Banks; Experimental Aspects of Small Punch Testing at Elevated Temperatures; *NPL Report DEPC MPE 029*, March 2006.

B Roebuck; Oxidation Studies on Miniaturised Mechanical Testpieces; *NPL Measurement Note, NPL (MN) 01*, April 2007.

6 EUROPEAN LINKS

Within the last 3 years the project consortium interacted with COST 538 and a CEN Working Agreement acting on SP tests. Within COST 538 NPL is involved in a Workpackage that, amongst other activities, will develop a library of microstructures for creep exposed material. Creep data for P12 and P91 steels will be reviewed and include a comparison of conventional and miniature tests on exposed and unexposed materials. Other outputs will include validated models for microstructural evolution and NDE techniques for materials and weldments.

Key points for SP creep tests noted in CEN TWA21 activities included a Code of Practice published as CWA 15627, December 2006. This document highlights the following:

- load and temperature control similar to existing creep standards
- preference for punch rather than a ball
- preferred testpiece to be 8 mm diameter and 0.5 mm thick (h)
- recommended rig geometries included
 - punch radius, r $1 < r < 1.25$ mm
 - aperture, $R = 2.00$ mm with chamfer
- If no prior knowledge load calculated from

$$F = \frac{10}{3} K_{sp} \sigma R^{-0.2} r^{1.2} h$$

where K_{sp} assumed to be 1.0 if not known.

In summary (*notes provided by Professor R Hurst, IE, JRC, Petten*)

- A Round Robin Small Punch testing programme on a CMV rotor steel was achieved amongst four European partners
- The use of simplified models proposed in the literature for correlating the punch load to the uniaxial stress in a conventional uniaxial creep test led to a significant grouping of all the SP results of the four laboratories into a single trend.
- This finding demonstrated that the lab to lab differences were simply due to having utilised two different punch diameters, and apart from this fully rationalised difference, the results were quite coherent among the partners.
- Nevertheless this Round Robin lent strong support to the demonstration that SP creep testing can be regarded as a robust, reproducible method, indeed therefore a good candidate for standardisation and eventually for industrial application to residual life analysis of plant components.

Within CEN TWA21 it was thought that the recommendations on dimensions represented an average of values across Europe. RWEnpower noted that as potential end user of TWA outputs they were seeking the ability to send samples for test to any laboratory across Europe and to get, in return, interchangeable data from a validated test geometry underpinned by repeatability and reproducibility tests. Thus, in conclusion, the current position in CEN is that:

- Draft Code of Practice prepared – CEN WS21
- Open for comments from SP Interest Group
- Document finalised as: CEN Workshop Agreement.

A proposed way forward for the CEN TWA might be:

- to define test conditions and procedures to give robust and repeatable results
- to produce Codes of Practice in formats suitable for becoming ISO norms
- to devise a verification test programme concentrating on a range of materials and key parameters from the Code of Practice
- to compare the SP sampling systems now available and recommend sampling procedures providing the non invasive nature of sampling.
- to consider new directions for use of the method, e.g. welds, coatings, non-metallic materials etc.

This may need a verification testing programme, that could in principle contain:

Phase 1 (for a quick-to-use CoP)

- Fixed geometry of apparatus and clamping
- Identically manufactured discs
- 3 types of materials only (ductility ranges)
- 2 temperatures
- Inert gas
- Comparable uniaxial creep tests

Phase 2 (for widespread application and improved accuracy)

- Annular clamping (bulge or drawing test?)
- Receiving hole diameter
- Geometry of the lip of the receiving hole
- Diameter of punch and shape
- Testpiece thickness
- Interrupted tests with geometrical measurements
- Supporting analytical programme (Finite Element)

Interested parties should contact Prof R Hurst at IE, JRC, Petten.

7 FORWARD LOOK

A brief debate at the UK Interest Group meeting on 28 March 2007 listed the following topics as being possibly worthy of further study:

- Repeatability of low load tests
- In-situ or interrupted tests
- Improved instrumentation for deformation studies
- Bend geometries as opposed to SP tests
- Tests with and without inert environments
- Improved strain measurement metrologies
- Uniaxial test rig designs, based on dc heating
- Modelling of uniaxial tests in thermal gradients
- Model sensitivities to input data and constitutive expressions
- Interlab tests with very well defined rig geometries
- Microhardness studies
- “Damage” evolution in testpieces.

A questionnaire is being sent to Interest Group members to prioritise topics for consideration of future support.

8 ACKNOWLEDGEMENTS

The DTI Materials Programme (Performance 2004-2007) provided the financial support for the work described in this Measurement Note. E.ON and Materials Department in the University of Wales, Swansea are thanked for the supply of the P12 and P11 steels respectively. Professor Roger Hurst of the Institute for Energy at JRC, Petten is acknowledged for the detailed comments on the CEN TWA on SP tests.

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APPENDIX A

Miniaturised Testing Interest Group Contact List – April 2007

Colin Austin
Materials Testing Team
Serco Assurance
Walton House
404, The Quadrant
Birchwood Park
Warrington, Cheshire, WA3 6AT
Tel:
Fax:
Email: colin.austin@serco.com

Jim Banks
Engineering and Process Control Division
National Physical Laboratory
Teddington
Middlesex TW11 0LW
Tel: 020 8943 7114
Fax: 020 8943 2989
Email: jim.banks@npl.co.uk

Pete Barnard
Alstom
Newbold Road
Rugby
Warwickshire CV21 2NH
Tel: +44 (0) 1788 531 529
Fax: +44 (0) 1788 531 309
Email: pete.barnard@power.alstom.com

Steve Brett
RWE Power International
RWE npower
Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
Tel: +44 (0) 1793/89 22 44
Fax: +44 (0) 1793/89 22 88
Email: steve.brett@rwenpower.com

Matthew Brooks
Engineering and Process Control Division
National Physical Laboratory
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6086
Fax: 020 8943 2989
Email: matthew.brooks@npl.co.uk

Rob Brooks
Engineering & Process Control Division
National Physical Laboratory
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6496
Fax: 020 8943 2989
Email: rob.brooks@npl.co.uk

Louise Brown
Engineering & Process Control Division
National Physical Laboratory
Hampton Road
Teddington
Middlesex TW11 0LW
Tel: +44 (0) 20 8943 8525
Fax: +44 (0) 20 8943 2989
Email: louise.brown@npl.co.uk

Turan Dirlik
Managing Director
Dirlik Controls Ltd
Albert Buildings
16A Albert Street
Rugby CV21 2RS
Tel: +44 (0) 1788 573 114
Fax: +44 (0) 1788 560 668
Email: info@dirlik.co.uk

Mark Evans
Interdisciplinary Research Centre
Materials Engineering Department
University College of Swansea
Singleton Park
Swansea SA2 8PP
Tel: 01792 295694
Fax: 01792 295693
email: m.evans@swansea.ac.uk

Simon Fenton
E.ON
Ratcliffe-on-Soar
Nottingham NG11 0EE
Tel: +44 (0) 1159 362 793
Email: simon.fenton@eon-uk.com

Tony Fry
National Physical Laboratory
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6220
Fax: 020 8943 2989
Email: tony.fry@npl.co.uk

Mark Gee
National Physical Laboratory
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6374
Fax: 020 8943 2989
Email: mark.gee@npl.co.uk

Chris Hamm
British Energy plc
Barnett Way
Barnwood
Gloucester GL4 3RS
Tel:
Fax:
Email: chris.hamm@british-energy.com

Jim Hannigan
Mitsui Babcock – Europe
Porterfield Road
Renfrew PA4 8DJ
Tel:
Fax:
Email: jhannigan@mitsuibabcock.com

Roger Hurst
European Commission
D-G JRC, Petten
Institute for Energy
PO Box 2
NL-1755 ZG Petten
The Netherlands
Email: roger.hurst@cec.eu.int

Tom H Hyde
University of Nottingham
University Park
Nottingham NG7 2RD
Tel: 0115 951 3830
Fax: 0115 951 3800
Email: thomas.hyde@nottingham.ac.uk

Jonathan James
University of Wales Swansea
Materials Centre of Excellence
School of Engineering
Singleton Park
Swansea SA2 8PP
Tel:
Fax:
Email: J.D.James@swan.ac.uk

Philip Jones
Alstom
Newbold Road
Rugby
Warwickshire CV21 2NH
Tel:
Fax:
Email: phil.jones@power.alstom.com

Jerry Lord
National Physical Laboratory
Hampton Road
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6340
Fax: 020 8943 2989
Email: jerry.lord@npl.co.uk

Malcolm S Loveday
National Physical Laboratory
Hampton Road
Teddington
Middlesex TW11 0LW
Tel: +44 (0) 20 8943 6900
Fax: +44 (0) 20 8943 2989
Email: malcolm.loveday@npl.co.uk

Gordon McColvin
Siemens Industrial Turbines
PO Box 1
Lincoln
Tel: 01522 584 240
Fax:
Email: gordon.mccolvin@industrial-turbines.siemens.com

Ken Mingard
National Physical Laboratory
Hampton Road
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6558
Fax: 020 8943 2989
Email: ken.mingard@npl.co.uk

Jeff Morfett
Instron Ltd
Coronation Road
High Wycombe
Buckinghamshire HP12 3SY
Tel: +44 (0) 1494 456 685
Fax: +44 (0) 1494 456 124
Email: jeff_morfett@instron.com

Peter Morris
Corus Research
Development & Technology
Swinden Technology Centre
Moorgate
Rotherham
S Yorkshire S60 3AR
Tel: +44 (0) 1709 825 327
Fax: +44 (0) 1709 825 337
Email: peter.f.morris@corusgroup.com

Steve Preston
Materials Testing Team
Serco Assurance
Walton House
404, The Quadrant
Birchwood Park
Warrington, Cheshire, WA3 6AT
Tel:
Fax:
Email: steve.preston@sercoassurance.com

Bryan Roebuck
Engineering and Process Control Division
National Physical Laboratory
Teddington
Middlesex TW11 0LW
Tel: 020 8943 6298
Fax: 020 8943 2989
Email: bryan.roebuck@npl.co.uk

Neville Shaw
RWE Power International
RWE npower
Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
Tel: +44 (0) 1793/89 38 14
Fax: +44 (0) 1793/89 22 88
Email: neville.shaw@rwenpower.com

Ali M Sisan
Defect Assessment Section
Structural Integrity Technology Group
TWI Ltd
Granta Park
Great Abington
Cambridge CB21 6AL
Tel: +44 (0) 1223 899 000 Ext 9612
Fax: +44 (0) 1223 893 303
Email: ali.sisan@twi.co.uk

Julian B Speck
TWI Ltd
Granta Park
Great Abington
Cambridge CB1 6AL
Tel: +44 (0) 1223 891 162
Fax: +44 (0) 1223 893 303
Email: julian.speck@twi.co.uk

Mike Spindler
Assessment Technology Group
British Energy
Barnett Way
Barnwood
Gloucester GL4 3RS
Tel:
Fax:
Email: mike.spindler@british-energy.com

Rachel Thomson
IPTME
Loughborough University
Loughborough
LE11 3TU
Tel: +44 (0) 1509 223 155
Fax: +44 (0) 1509 223 949
Email: r.c.thomson@lboro.ac.uk

Sun Wei
University of Nottingham
University Park
Nottingham NG7 2RD
Tel: 0115 951 xxxx
Fax: 0115 951 xxxx
Email: w.sun@nottingham.ac.uk

Jonathan Wells
RWE Power International
RWE npower
Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
Tel: +44 (0) 1793
Fax: +44 (0) 1793
Email: jonathan.wells@rwenpower.com

APPENDIX B

Project Rationale and Objectives

Materials in plant and structures are expected to endure in service for years or decades, far longer than the period available for testing or evaluating new systems. They often experience high fluctuating loads and temperatures and operate in environmental conditions that are very detrimental to long-term properties. Design procedures must ensure that failure does not occur during the expected component life. The remanent lifetime of components is often assessed using destructive tests on specimens taken from the actual component. Material is scarce (or only available in thin section) and tests on ‘miniaturised’ specimens allow a more extensive test programme and indeed may be the only available test route. Miniature test pieces thus have good prospects for use in predicting remanent life of plant and equipment provided that the data generated can be proven to be reliable. The key technical issues can be summarised as:

- Existing disc punch tests measure rupture time; can this be correlated with uniaxial test data, other miniature tests and plant behaviour.
- Tests are not standardised or even fully characterised.
- Long-term creep data are not available for superalloys.
- Linking mechanical data from miniature test procedures with microstructural changes.

This project will validate the use of miniaturised test techniques by a comparison of properties obtained from miniature tests with those from conventional sized tests. Protocols for the use of the technique will be developed, together with an understanding of microstructural changes, through tasks to:

- to optimise the test conditions of relevant miniature tests and correlate the results with those from full size samples.
- to develop a suitable numerical model of the disc test.
- to develop protocols and good testing practice for relevant tests, including sampling procedures and quantification of uncertainties.
- to investigate the protocols through one or more inter-laboratory exercises.
- to evaluate microstructural techniques for characterising the evolution of degradation mechanisms, including physical damage e.g. cavitation and cracking, for use in the estimation of remanent life.

Materials that are being investigated include low alloy ferritic steels, while an additional specific target is for quantification of degradation mechanisms in the miniature tests, including physical damage e.g. cavitation and cracking.