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The University of Nottingham

# Application of Impression Creep Test Data for the Assessment of Service Exposed Power Plant Components

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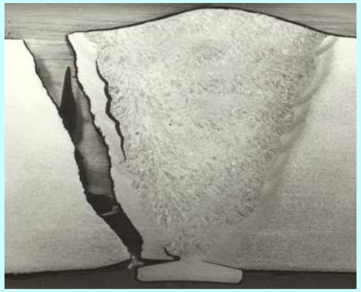
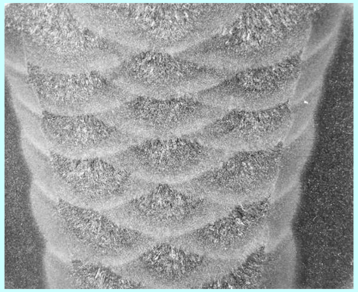
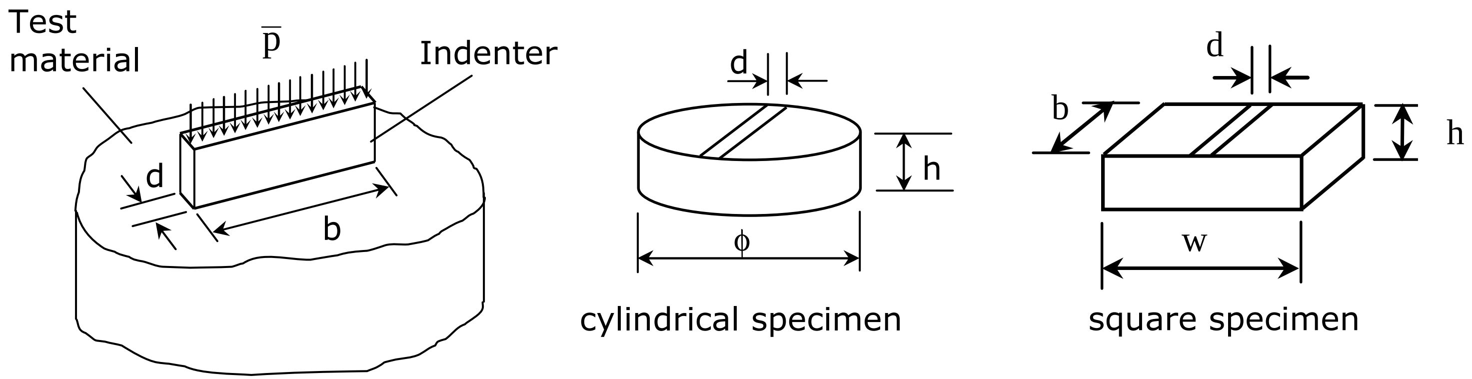
# Introduction

- The work on impression creep testing at the University of Nottingham started in 1992. The test method using a rectangular indenter was developed in 1995.
- The original intention was to use the test method to determine the secondary creep properties for the heat-affected zones (HAZs) in welds.
- Since then it has been used in a number of EPSRC, EU and Industry projects, which have involved the failure assessments of welds & weld repairs using computational modelling.
- More recently, impression creep data obtained from ex-service on-site scoop samples have been used to assist with in remnant life evaluations, in conjunction with uniaxial data.
- Currently, the test method is attracting significantly increasing attention from industrial and research organizations involved in power plant material and component assessments.





# The Test Method




- **Impression creep testing involves the application of a steady load to a flat-ended indenter, placed on the surface of a material at high temperature.**
- **The displacement-time record from such a test is related to the creep properties of a relatively small volume of material in the immediate vicinity of the indenter.**
- **The indenter can be cylindrical or rectangular (d ~ 0.8-1mm, h ~ 2-2.5mm, w ~ 8-10mm).**
- **Conversion relationships have been established based on the Reference Stress Method.**
- **The technique can be used for stepped-load and stepped-temperature situations.**

***Hyde, T. H., Sun, W. and Becker, A. A.***, Analysis of the impression creep test method using a rectangular indenter for determining the creep properties in welds, *Int. J. Mech. Sci.*, **38** (10), 1996, 1089-1102.

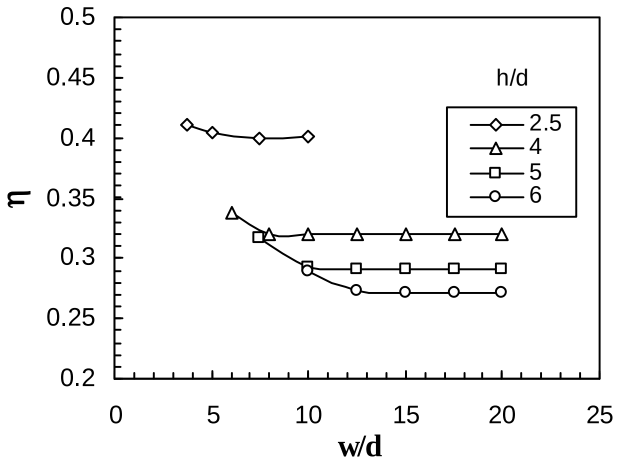
# Conversion Relationships

**A mechanics-based, reference stress approach has been used to to convert the mean pressure under the indenter to the corresponding uniaxial stress, i.e.**

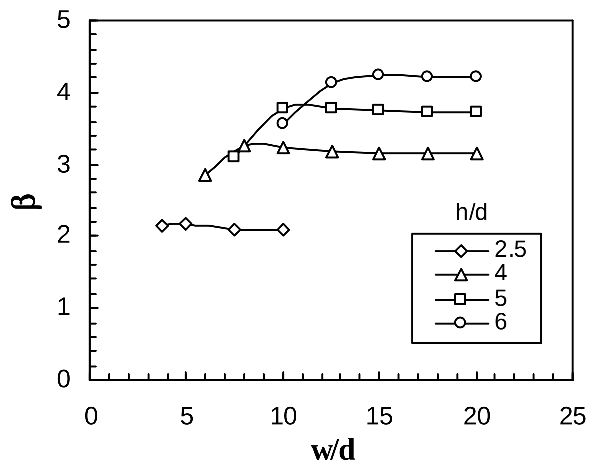
$$\sigma = \eta \bar{p}$$

**and to convert the load-line direction impression creep displacement to the corresponding uniaxial creep strain, i.e.**

$$\varepsilon^c = \frac{\Delta^c}{\beta d}$$



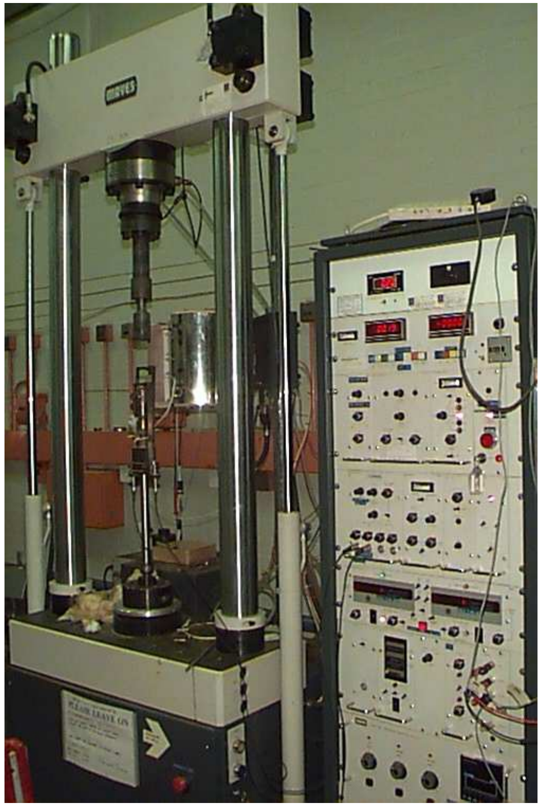

Variations of reference parameter η with w/d, for a range of h/d values.

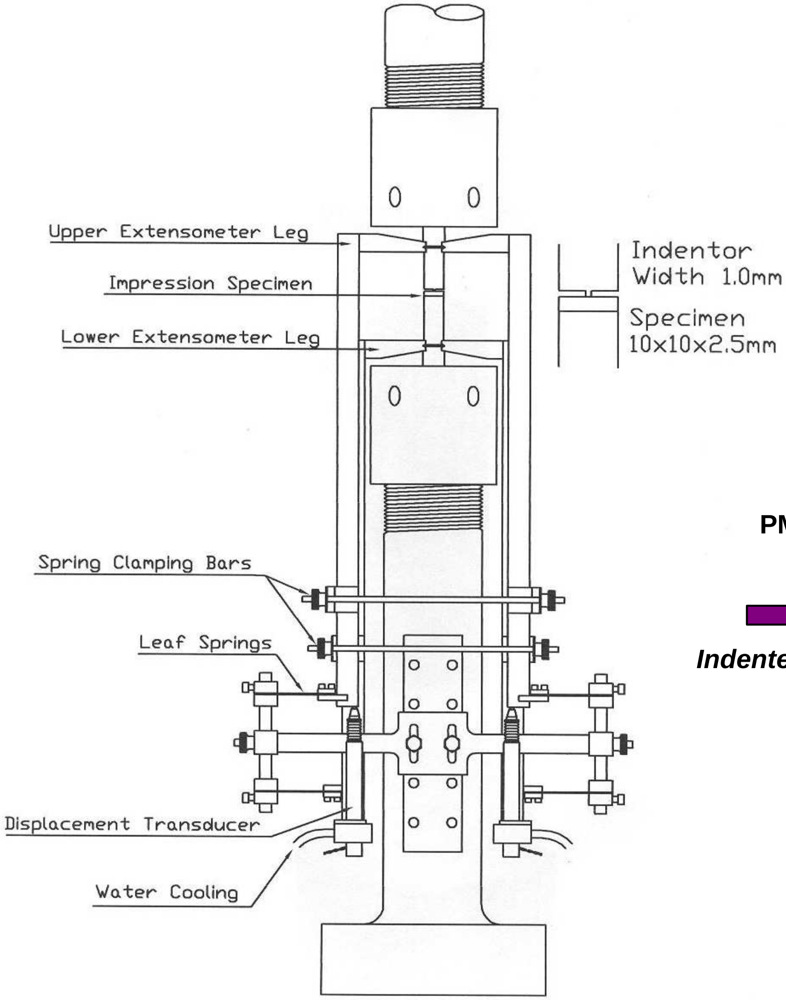



Variations of reference parameter β with w/d, for a range of h/d values.

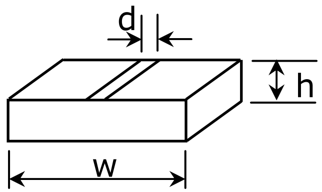
***Hyde, T. H. and Sun, W.***, Evaluation of the conversion relationship for impression creep testing. *Int. J. of Pres. Ves. & Piping* **86** (11), 2009, 757-763.

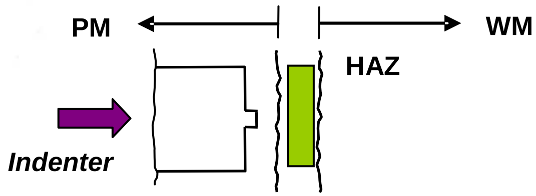
# Test Rig and Specimens

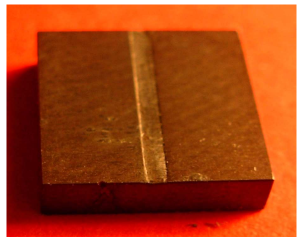




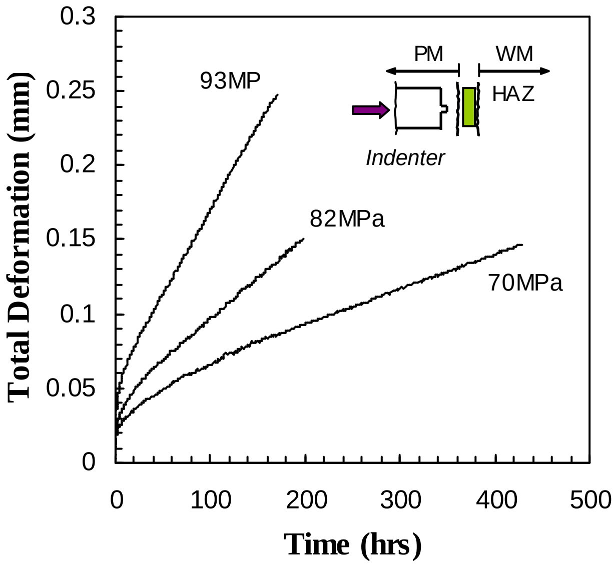

HIGH TEMPERATURE CREEP TEST EXTENSOMETER



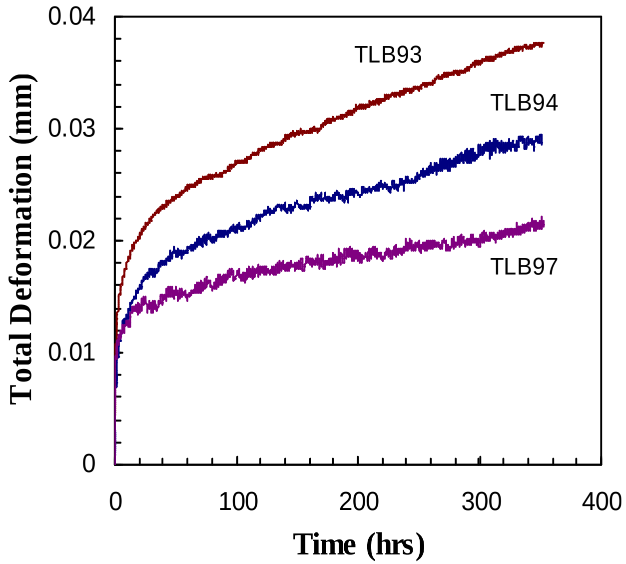



# Typical Results – *Test Curves*

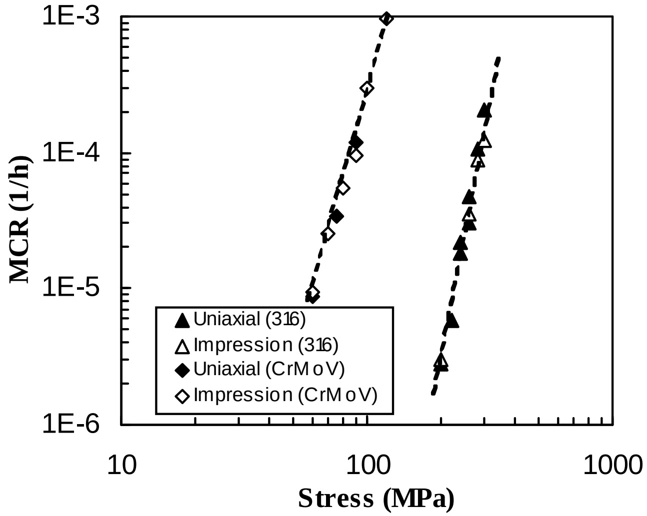



Total impression deformations versus time for the HAZ material in a P91 weld at 650ºC (rectangular indenter and square specimen: d = 0.8mm, h = 2mm, w = 8mm).



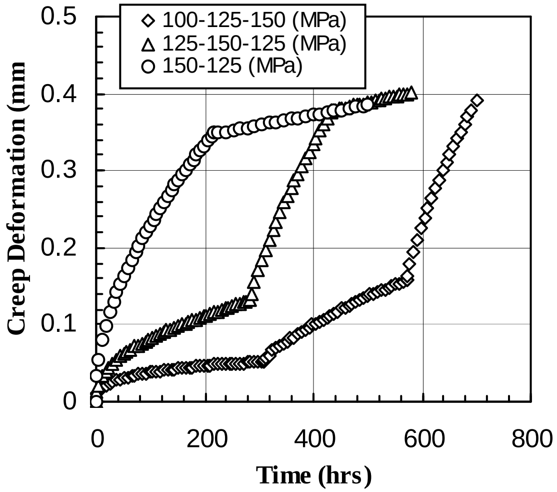

Total impression deformations versus time at 90 MPa and 600º C obtained from three different ex-service ½CrMoV steam pipe samples (d = 1mm, h = 2.5mm, w = 10mm).

# Typical Results – *Comparison with Uniaxial Data*

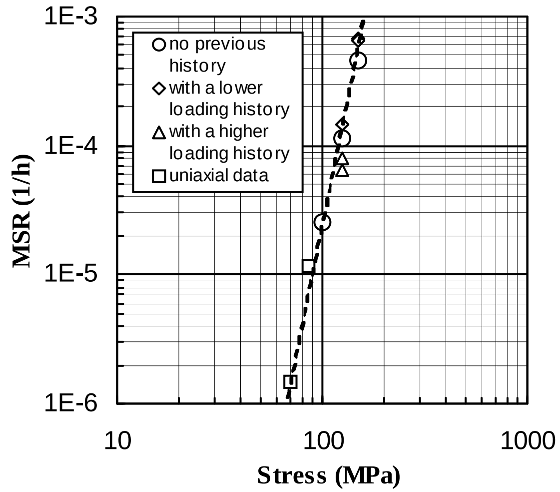



Minimum creep strain rate data for 316 stainless steel at 600°C and 2-1/4Cr1Mo weld metal at 640°C, obtained from uniaxial and impression creep tests.

# Typical Results - *Stepped-Load Tests*



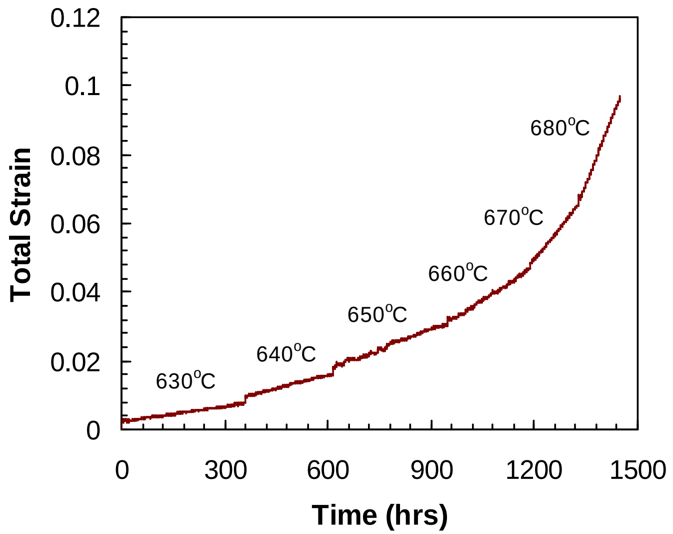

Creep deformation of impression creep tests for the 1/2Cr1/2Mo1/4V steel at 565°C, obtained from multi-step tests (rectangular indenter and square specimen: d = 1mm, h = 2.5mm, w = 10mm).



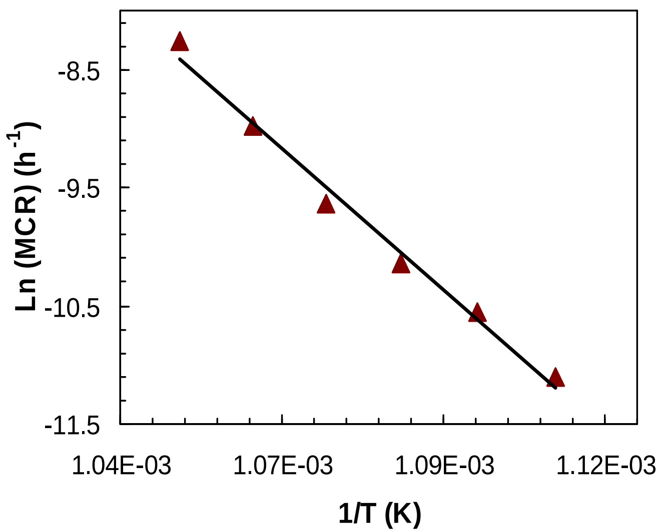

Minimum creep strain rate data for the 1/2Cr1/Mo1/4V steel at 565°C, obtained from multi-step impression tests and uniaxial creep tests.

***Hyde, T. H. and Sun, W.***, Multi-step load impression creep tests for a 1/2CrMoV steel at 565o C, *Strain* **37**, 2001, 99-103.

# Typical Results - *Stepped-Temperature Tests*




Converted uniaxial strain with time for an ex-service CrMoV material, subjected to stepped-temperatures of 630, 640, 650, 660, 670 and 680°C, at 40MPa.




Minimum creep strain rates versus 1/T, obtained from impression creep test for an ex-service CrMoV material at 40MPa and 630, 640, 650, 660, 670 and 680°C

***Sun, W., Hyde, T. H. and Brett, S. J.***, Application of impression creep data in life assessment of power plan materials at high temperatures. *Proc. Instn Mech. Engrs. Part L, J. of Materials: Design and Applications,* **222**, 2008, 175-182.

# Summary of Impression Creep Tests Performed

| Materials | Temp. (°C) | Projects | Organisations | Years |
|---|---|---|---|---|
| CrMoV welds | 640 | Industry EPSRC | E.ON, British Energy RWE npower | 1993-1996 1996-1999 |
| 316 | 600 | Industry | TWI | 1998 |
| 316H | 550 | Industry | British Energy | 1999 |
| P22, P91 welds | 550, 625, 650 | EPSRC, EU | E.ON, RWE npower, CESI, ISQ, SPG and others | 2000-2005 |
| Mod9Cr Ex-service 1/2CrMoV | 570-680 | Industry | RWE npower | 2000- |
| Grade 91 | 600 | Industry | Structural Integrity Associates | 2007-08 |

# Plant Application of the Test Data

- In order to realise its full value impression creep testing should be able to produce creep and creep strain rate data equivalent to, or convertible to, those obtained by full-scale conventional creep testing.
- Small-scale sampling and impression creep testing has been used by RWE npower as part of its methodology for managing the risk of potential failures of parent material components.
- Data have been used for integrity assessments of retrofit Grade 91 headers and aged CrMoV steam pipework.
- In particular, the data have been used for “ranking” the creep strength of the components sampled in–situ; this information can be of significant value to plant operators.

# Sampling of Scoop Samples

- **Scoop samples are shallow discs, typically 24-26mm in diameter and 3.5-4.5mm in thickness. A Surface Sampler (SSAM) has been used to remove the scoop samples. A typical cutting time is 1.5-1.75 hrs.**
- **For the subsequent testing and data processing, each scoop sample is individually labelled and marked.**
- **A test specimen of 10×10×2.5mm requires the minimum thickness of the scoop sample to be about 3.2mm.**

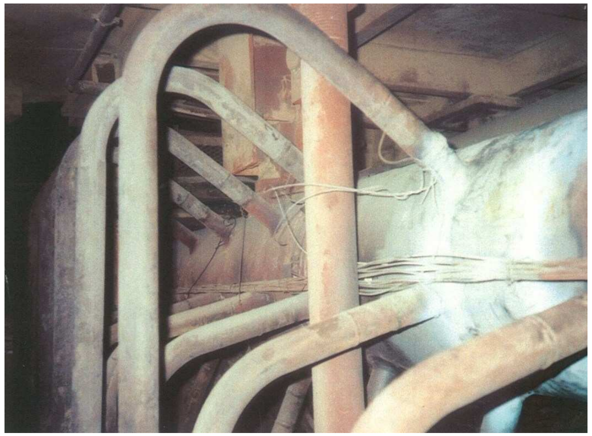
Scoop sampling in process on a pipework

A typical scoop sample

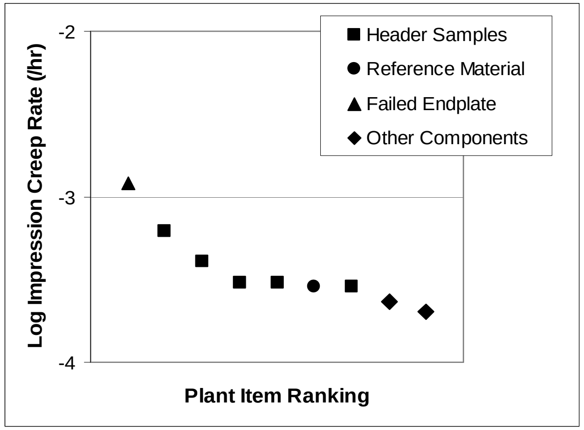
# Application to Retrofit Grade 91 Headers

- **Following a number of premature Type IV failures of grade 91 components in the 1990s, RWE npower carried out a survey of its own retrofit grade 91 headers looking for any that could have been vulnerable to early failure.**

- **In-situ scoop samples were removed from suspect headers and were impression creep tested. The data were compared with a weak grade 91 bar which had been creep tested using both small scale and conventional methods in order to provide a reference material.**



Modified 9Cr header

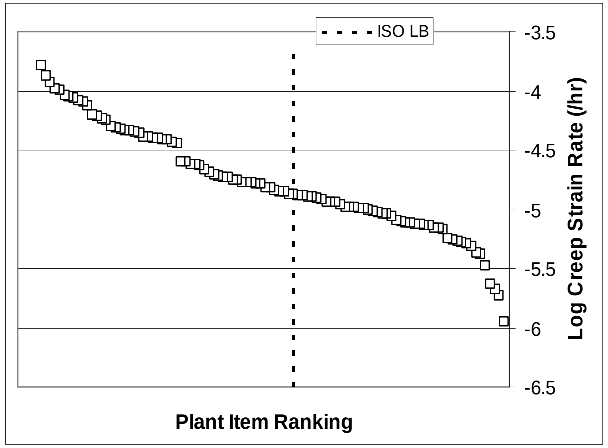



Impression creep strain rates obtained from samples from the suspect header compared to a sample from a weak failed endplate and samples from other components (600°C, 166.5MPa).

**Brett, S. J.** Early Type IV cracking on two retrofit grade 91 steel headers. *IIW Int. Conf. on Safety and Reliability of Welded Components in Energy and Processing Industry*, Graz, Austria, 10–11 July 2008.

# Application to Aged CrMoV Steam pipework

- **Most of the older coal–fired power plants currently operating in the UK were built with ½CrMoV steam pipework, which have now operated for well beyond their original design life, making it necessary also to consider the possibility of parent failure.**
- **Small-scale sampling and impression creep testing is being used by RWE npower as part of its methodology for managing this risk.**
- **Those pipework components shown to have the weakest creep strength can be selected for periodic monitoring within the broader inspection programme.**
- **The aim is again to increase the probability of identifying damage at an early stage.**




Impression creep strength ranking plot for ½CrMoV (600°C, 96.7MPa).

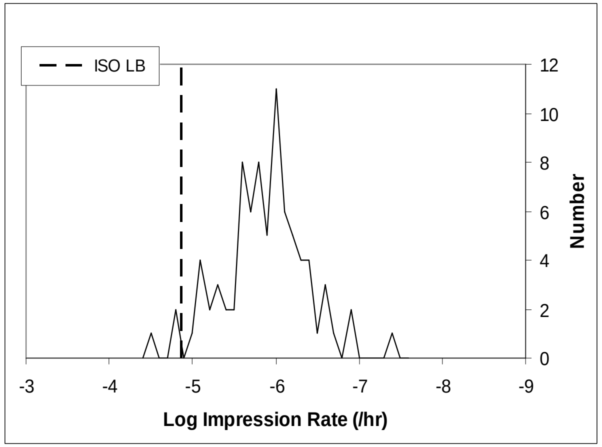
# Placing an Individual Material within a Creep Strength Scatter Band

**❑In order to compare the creep strengths of components of significantly different plant age, or samples obtained from the same system or component at different stages of life, it may be more appropriate to use a correction factor to make comparisons on the basis of a common operating age.**

**❑Small-scale sampling and impression creep testing is being used by RWE npower as part of its methodology for managing this risk.**

**❑Sufficient data have now been obtained from ex-service ½CrMoV samples at different operating ages to allow an empirical correction for operating hours to be applied.**

**❑Once such a correction has been made the range of values derived effectively represents the creep strength scatter band.**




Histogram showing the ½CrMoV data, corrected for operating hours at the time of sampling to reflect strength at the start of life.

# "Standardization"?

- The impression creep test method, using a rectangular indenter, has been used extensively in the last 10 years for a number of UK, EU and industrial projects.
- A number of leading industrial organizations have already built or are in the process of developing their own test rigs.
- In order for the operators of power plant to use the technique as an integral part of the remanent life strategy, standardisation of the test method is necessary.
- This would lead to the acceptance of the approach by power plant operators as a standard technique and allow consistent data to be generated by different laboratories.

**Hyde, T. H., Sun, W. and Brett, S. J.**, Some recommendations on standardization of impression creep testing. *Proc. of ECCC Conf. on Creep and Fracture in High Temperature Components - Design and Life Assessment*, April 2009, Dübendorf, Switzerland. p. 1079-1087.

# Discussion and Future Work

- ❑The impression creep test method has been well established; important applications are in determining "bulk" creep properties at local regions (e.g. HAZ) and in determining the relative creep strengths from scoop samples for on-site assessment.

- ❑Ranking tests, to prioritise NDT, have been, and are currently are being increasingly used.

- ❑A broader goal is to obtain an estimate of the range of creep strength present in the pipework system in order to evaluate the necessity and timescale for pipework replacement.

- ❑The dual data (impression and uniaxial) produced from pipework and bends are being used to derive empirical evidence to validate the theoretical relationship between the two types of test over a wide range of testing conditions, potentially allowing for extrapolation to service conditions.

- ❑A number of industrial organisations are evaluating the impression creep test method as a "standard" route for producing material data. Standardization of the testing method needs to be considered.