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SMALL SPECIMEN CREEP TESTING AND APPLICATION FOR POWER PLANT COMPONENT REMAINING LIFE ASSESSMENT

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ABSTRACT
This paper contains a description of some recent progress on small specimen creep testing and its applications for the assessment of service-exposed power plant components at elevated temperatures. Firstly, the reference stress method and the concept of equivalent gauge length are introduced, which form the basis for processing and interpreting the data from small specimen creep tests. Then, some fundamental aspects on the development of several commonly used small specimen creep test techniques, including the impression creep test, small punch creep test, small ring creep test and small two bar creep test, are briefly outlined. Typical examples of the application of the small specimen creep test methods, in determining creep deformation and rupture life data, are given. The applications of the test data to assist with the life assessment of power plant components, particularly those with service-exposed materials, using data obtained from scoop samples, are described. Finally, the future possibilities for the exploitation of small specimen creep test techniques are briefly discussed.

Keywords: small specimen creep testing, power plant components, life assessment.

1. INTRODUCTION

Power plants and chemical plants may operate at elevated temperatures for extended periods of time, e.g. more than 30 years. During this time, the material used in the construction of the plants degrades and the creep strength of the material reduces. NDT and small specimen test techniques can be employed to sample and test the material. For this reason, various small or miniature specimen test methods have been developed and used [**1**]. The latest work on small specimen creep testing involves the development of specimen types which are suitable for obtaining creep strain rate and creep rupture data [**2**]. The small test specimens used for these types of tests can be obtained from small button-shaped (scoop) samples (~ 25 mm in diameter and 2-4 mm in thickness), which are removed, for example, by a non-destructive sampling technique.

Small specimen creep testing has become increasingly attractive because some power plant components are now operating beyond their original design life, and economic, “non-invasive” and reliable testing techniques are required when performing remaining life evaluations [**3,4**]. Data from small volumes of materials have a direct input into remaining life and ranking studies, thereby improving the confidence of plant/component life prediction and managing the potential risk [**5**]. Such data can also be used to generate creep constitutive laws for weld materials and for local structures generated during the welding process [**6**]. In addition, the ability to measure creep properties from a small volume of material has the potential to, rapidly and economically, support the development of new high temperature, exotic alloys.

2. THEORETICAL BASIS FOR SMALL SPECIMEN CREEP TESTING

2.1 Stationary State Creep Deformation

In general, the principle of converting the non-conventional, small specimen creep test data to the corresponding uniaxial data is based on the inverse application of the reference stress method. For some components and loading modes, it is possible to obtain analytical expressions for steady-state creep deformation rate, $\dot{\Delta}_{ss}$ [e.g. **7-9**]. For components made from a material obeying Norton's power law, i.e. $\dot{\varepsilon}^c = B\sigma^n$, the general form of the solution is:

$$\dot{\Delta}_{ss} = f_1(n)\, f_2(\text{dimension})\, B\sigma_{nom}^{\;n} \qquad (1)$$

where f_1 (n) is a function of the stress index, n, f_2 (dimensions) is a function of the component dimensions and σ_{nom} is a conveniently determined nominal stress for the component and loading.

2.2 Reference Stress Method

By introducing an appropriate scaling factor, α, for the nominal stress, Equ. (1) can be rewritten as:

$$\dot{\Delta}_{ss} = \frac{f_1(n)}{\alpha^n}\, f_2(\text{dimension})\, B(\alpha\sigma_{nom})^n \qquad (2)$$

Choosing α (= η) so that $f_1(n)/(\eta)^n$ is independent (or approximately independent) of n, then Equ. (2) can be further simplified to:-

$$\dot{\Delta}_{ss} \approx D\dot{\varepsilon}^c(\sigma_R) \qquad (3)$$

where D is the so-called reference multiplier [D = $(f_1(n)/(\eta)^n)f_2$ (dimensions)] and $\dot{\varepsilon}^c$ (σ_R) is the creep strain rate obtained from a uniaxial creep test at the so-called reference stress, σ_R (= $\eta\sigma_{nom}$). The reference multiplier, D, has units of length, and can generally be defined by D = βd, where d is a conveniently chosen "characteristic" component dimension. Therefore, if the values of η and β are known, for the known loading mode and component dimensions, the corresponding equivalent uniaxial stress can be obtained from the expression σ_R (= $\eta\sigma_{nom}$), and the corresponding uniaxial creep strain rate can be obtained using Equ. (3) if $\dot{\Delta}_{ss}$ is known.

If an analytical solution can be obtained, substituting two values of n into the expression $f_1(n)/\eta^n$ and equating the two resulting expressions allows the value of η to be determined. Hence, σ_R (= $\eta\sigma_{nom}$) and D can be obtained. This approach was proposed by MacKenzie [**10**]. However, analytical solutions only exist for a small number of, usually, relatively simple components and loadings.

If, for example, computed solutions, using the finite element method, are obtained for a creep problem, for several n values, but keeping all other material properties, loading and component dimensions the same, then σ_R can be obtained. This is done by guessing several values of α, normalising the steady-state value of displacement rate, $\dot{\Delta}_{ss}$, with respect to $B(\alpha\sigma_{nom})^n$ and hence finding the value of α which renders $[\dot{\Delta}_{ss} / (B(\alpha\sigma_{nom})^n)]$ independent of n (i.e. $\alpha = \alpha_R = \eta$). This process is most easily visualised by plotting log $[\dot{\Delta}_{ss} / (B(\alpha\sigma_{nom})^n)]$ against n, for various values of α, as illustrated in Fig. **1**. It can be seen that the straight lines produced, using all of the α values, have approximately the same intercept on the log $[\dot{\Delta}_{ss} / (B(\alpha\sigma_{nom})^n)]$ axis. This intercept is equal to the logarithm of the reference multiplier, D.

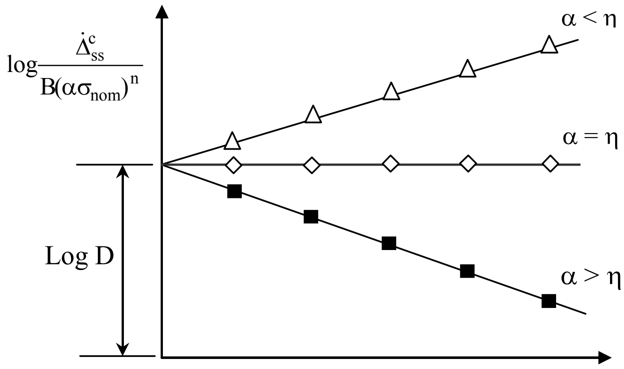

Fig. **1** Schematic diagram illustrating a method which can be used to obtain reference parameters from FE analysis.

2.3 Equivalent Gauge Length

For a conventional uniaxial creep test, the creep strain at a given time is usually determined from the deformation of the gauge length (GL). If the gauge length elongation is Δ^c and the elastic portion is neglected, then

$$\varepsilon^c \approx \frac{\Delta^c}{GL} \quad (4a)$$

For non-conventional small specimen creep tests, an equivalent gauge length (EGL) [**11**] can be defined, if the measured creep deformation can be related to an equivalent uniaxial creep strain, in the same form as that of Equ. (4a), i.e.

$$\varepsilon^c \approx \frac{\Delta^c}{EGL} \quad (4b)$$

The EGL is related to the dimensions of the specimen and in some cases may be related to the time-dependent deformation of the test specimen. The creep strain and creep deformation given in Equ. (4b) may be presented in a form related to the reference stress, σ_R, i.e.

$$\varepsilon^c(\sigma_R) \approx \frac{\Delta^c}{D} \quad (5)$$

in which D (= βd) is the reference multiplier, which is, in fact, the EGL for the test. In some cases, the geometric changes, which occurs due to the time-dependent deformation of the component, are small (e.g. for impression creep tests), and in such cases, the effects of geometric changes on D (EGL) may be neglected.

3. NON-STANDARDED SMALL SPECIMEN CREEP TESTING METHODS

3.1 Impression Creep Test (ICT)

The impression creep testing technique involves the application of a steady load to a flat-ended rectangular indenter, Figs. **2**(a) and **3**(a), placed on the surface of a material at elevated temperature, from which the small load-line displacement is measured.

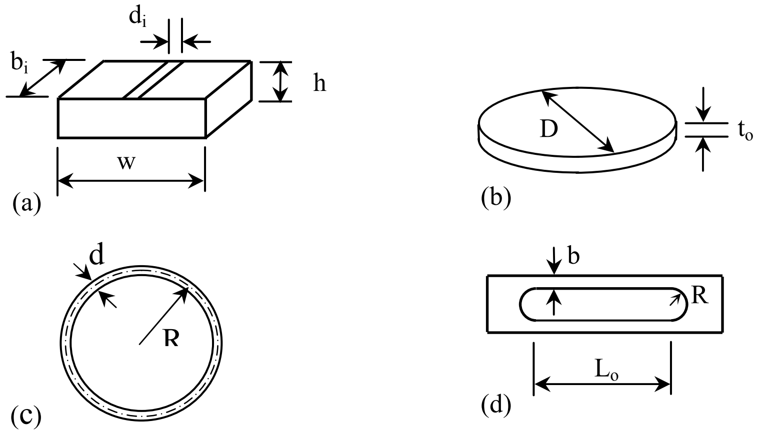

Fig. **2** Small creep test specimens: (a) ICT specimen ($w = b_i \approx 10mm$; $d_i \approx 1mm$; $h \approx 2.5mm$); (b) SPT specimen ($D \approx 8mm$; $t_o \approx 0.5mm$); (c) SRT specimen ($R \approx 5mm$, $d \approx 1mm$ and depth $b_o \approx 2mm$); and (d) TBT specimen ($L_o \approx 5\text{-}10mm$; $b \approx 1\text{-}2mm$; $R \approx 2\text{-}3mm$; thickness $d \approx 1\text{-}2mm$).

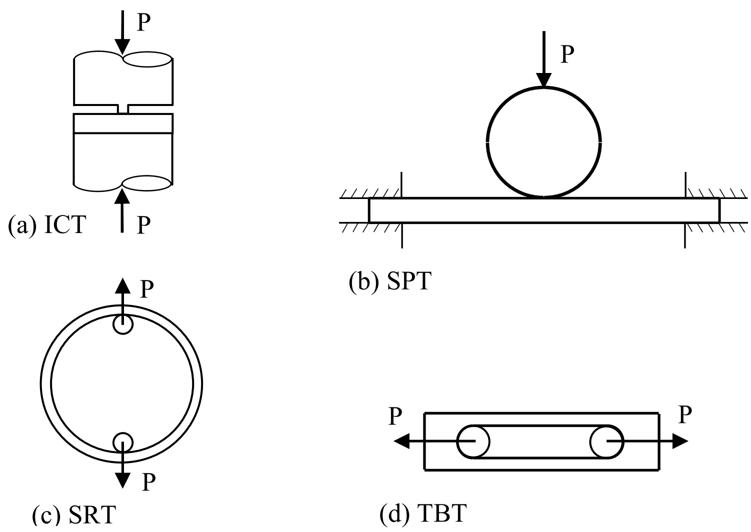

Fig. **3** Schematics diagrams showing the small specimen loading arrangements: (a) ICT; (b) SPT; (c) SRT; and (d) TBT.

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. Tests are usually performed with a constant load level, at a fixed temperature. For the rectangular indenters, the reference stress approach has been used as the basis [**12**] for determining the corresponding equivalent uniaxial stress, σ, and creep strain, ε^c. These are related to the applied mean indenter pressure, $\overline{p}$, and the measured impression creep displacement, Δ^c, via relationships [**12**]:

$$\sigma = \eta \bar{p} \qquad (6a)$$

and $$\varepsilon^c = \frac{\Delta^c}{\beta d_i} \qquad (6b)$$

The η and β in Equs. (6) are non-dimensional conversion factors. The η and β values for the recommended geometry ($w \times b_i \times h$ = 10×10×2.5 mm) are $\eta \approx 0.4$ and $\beta \approx 2$ [**12**], for an indenter width of d_i = 1 mm. These are independent of material properties and do not vary with impression depth provided Δ^c is relatively small compared to the specimen thickness, h. The technique has been used for a wide range of materials (e.g. low alloy ferritic CrMoV steels, stainless steels, high chromium martensitic steels such as P91 and T91, and P92). A typical set of data obtained from such tests for a ½CrMoV steel is shown in Fig. **4**. The slight fluctuations in the data are mainly caused by temperature variations within the furnace and within the laboratory. However, it can be seen that these variations are typically well within $\pm$1 μm.

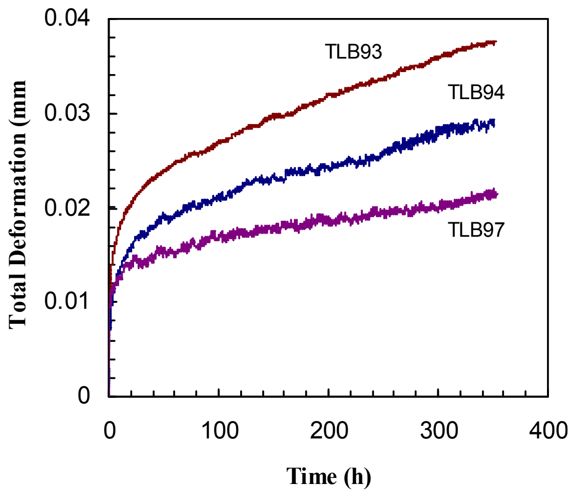

Fig. **4** Impression deformations with time at 90 MPa and 600° C obtained from ex-service ½CrMoV steam pipe samples.

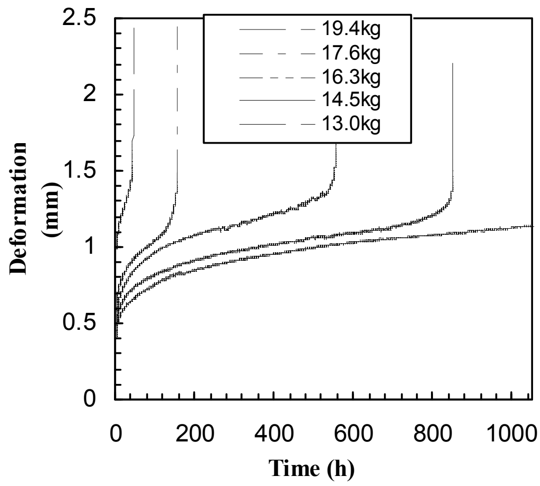

Fig. **5** Typical small punch test data for a P91 steel at 650°C.

3.2 Small Punch Creep Test (SPT)

The small punch creep test involves the application of a central load, through a spherical punch or a ball, to a thin disc, at high temperatures. A typical small punch test specimen and experimental set-up are shown in Figs. **2**(b) and **3**(b), respectively; typical specimens measure 8 mm in diameter and 0.5 mm in thickness [e.g. **13,14**]. The test involves the measurement of relatively large deformations, producing a deformation curve leading to fracture. The fact that fracture occurs is a particularly attractive feature of this type of test as the possibility of estimating the creep rupture data for the material exists. Empirical relationships between the applied load, P, the "membrane stress", σ, the equivalent strain at the edge of contact, ε, and the total deformation, Δ, have been obtained. For the case of a_p = 2.0 mm and R_s = 1.25 mm, the P/σ ratio and the strain, ε, for Δ > 0.8 mm, are given by [**13,14**]:-

$$P/\sigma = 1.72476\Delta - 0.05638\Delta^2 - 0.17688\Delta^3 \qquad (7a)$$

$$\varepsilon = 0.17959\Delta + 0.09357\Delta^2 + 0.00440\Delta^3 \qquad (7b)$$

The variation of the maximum P/σ, with a_p, R_{sp} and t_o, for $\Delta > 0.8$ mm, has been obtained and this leads to an expression for σ of the form:-

$$\sigma = \frac{0.3}{K_{sp}} \frac{P a_p^{0.2}}{R_s^{1.2} t_o} \tag{8}$$

where a_p, R_s and t_o are the radius of the unclamped region of the disc between the supports, the radius of the punch and the initial thickness of the disc, respectively; K_{sp} is a non-dimensional correlation factor, which is determined empirically for the particular material. The units for Equs. (7b) and (8) are: dimensions and deformation in mm, stress in MPa and force in N. Typical creep deformation versus time curves are shown in Fig. **5**, which exhibits similar behaviour to that of typical uniaxial curves, i.e. there appears to be "primary", "secondary" and "tertiary" regions. However, a high level of local plasticity occurs at the start of the test, which could have a significant effect on the material, and therefore, the subsequent "creep dominant" deformation.

3.3 Small Ring Creep Test (SRT)

This small specimen type (patent application PCT/GB2008/001547) is an elliptical ring (a particular case of which is that of a circular ring), diametrically loaded in tension, as illustrated in Figs. **2**(c) and **3**(c). Load-line deformation versus time curves are obtained during the test. It is designed to be "flexible" to enable small strains to be related to relatively large deformations. However, the deformations do not significantly affect the conversion parameters, i.e. η and β, which enables highly accurate secondary creep properties to be obtained.

The steady-state creep solution for the load-line deformation rate, $\dot{\Delta}_V$, of an elliptical ring, obeying a Norton's law ($\dot{\varepsilon}^c = B\sigma^n$), has been obtained, based on the principles of virtual complimentary work and stationary complimentary energy. The conversion relationships (η and β) for a range of geometries have been obtained by use of the reference stress approach. Detailed analytical procedures have been reported [**11**]. The main relationships are:

$$\dot{\varepsilon}^c(\sigma_{ref}) = \frac{d}{4ab\beta}\dot{\Delta}_V \tag{9a}$$

$$\sigma_{ref} = \eta \frac{Pa}{b_o d^2} \tag{9b}$$

For a circular ring (a = b = R), Equs. (9) become:-

$$\dot{\varepsilon}^c(\sigma_{ref}) = \frac{d}{4R^2\beta}\dot{\Delta}_V \tag{10a}$$

$$\sigma_{ref} = \eta \frac{PR}{b_o d^2} \tag{10b}$$

The test results for circular (a/b = 1) rings, with R/d = 5, for a P91 steel at 650°C, with a range of equivalent uniaxial stresses, are shown in Fig. **6**.

3.4 Small Two-Bar Specimen Creep Test (TBT)

A new small specimen test type, suitable for use in obtaining both uniaxial creep strain rate data and creep rupture life data, is shown in Figs. **2**(d) and **3**(d) [**15**]. The specimen has a simple geometry and can be conveniently machined and loaded (through pin-connections) for testing. Conversion relationships between the applied load and the corresponding uniaxial stress, and between the measured load-line (pins) deformation, and the corresponding uniaxial minimum creep strain rate, have been obtained, based on the reference stress method. The η-value (≈ 1) is found to be practically independent of dimension ratios, and the β-value varies with dimension ratios, and for $L_o/b = 4.5$ and $R/b = 1.25$, $\beta = 1.46$ [**15**]. Test results obtained from the two-bar specimens, for a P91 steel, at 600°C, Fig. **7**, have been used to validate the test method. It can be seen that the deformation curves obtained from the two bar test specimens are very similar to those obtained from typical uniaxial specimen tests.

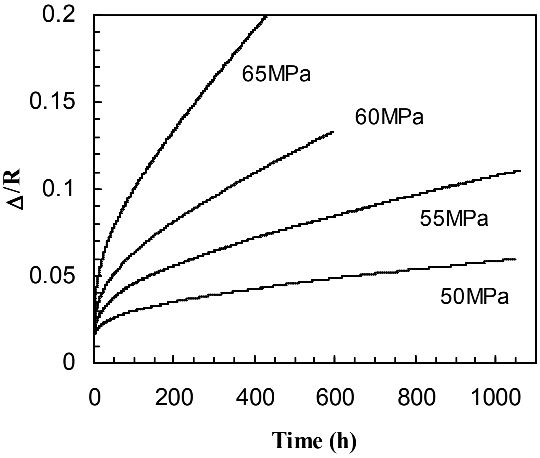

Fig. **6** Deformation (Δ/R) versus time curves obtained from circular rings for a P91 steel at 650° C.

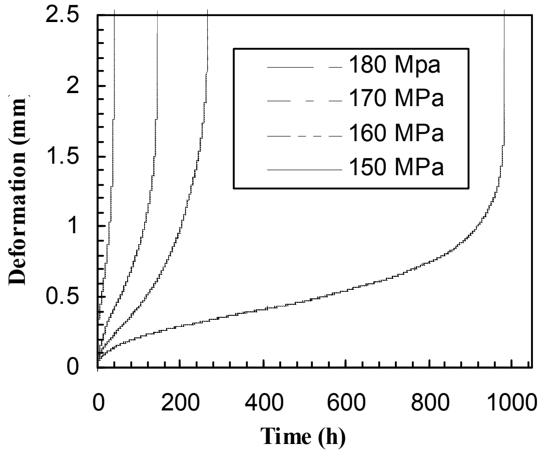

Fig. **7** Deformation versus time curves obtained from two bar specimens for a P91 steel at 600° C.

4. DETERMINATION OF CREEP DATA FROM SMALL SPECIMEN TESTS

4.1 Minimum Creep Strain Rate Data

Minimum creep strain rate data obtained from ICT specimen tests carried out on a 0.5CrMoV steel, at 640°C, and on a 316 stainless steel, at 600°C, are given in Fig. **8** [**4**].

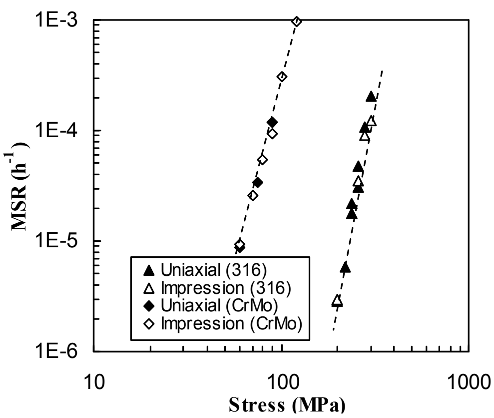

Fig. **8** Minimum creep strain rate (MSR) data for 316 stainless steel at 600° C and 2-1/4Cr1Mo weld metal at 640°C, obtained from uniaxial and impression creep tests.

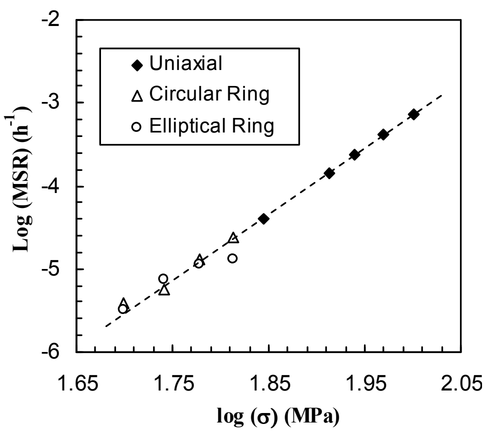

Fig. **9** Minumum creep strain rate data for a P91 steel at 650°C obtained from uniaxial and ring tests.

Also shown in Fig. **8** are the corresponding uniaxial creep test data. It can be seen that, in all cases, good agreement exists between the uniaxial creep test data and the corresponding ICT data. Fig. **9** shows the results obtained from uniaxial creep data and the corresponding SRT data for a P91 steel, at 650°C [**16**]. It can be seen that the two sets of results agree very well. It should be noted that the stress levels for which the ring test results were obtained produced easily measurable deformations with high accuracy. These types of results would be at the limit of what would be achievable, with acceptable accuracy and sensitivity of measurement, from impression creep tests.

4.2 Creep Rupture Life Data

Creep deformation curves obtained from two-bar specimen tests are shown in Fig. **7** for a P91 steel at 600°C. The creep rupture data obtained from these tests are compared with the corresponding uniaxial data in Fig. **10**. The results given in Figs. **7** and **10** clearly show that the two-bar specimen type is capable of producing the full uniaxial creep strain curve including rupture data. Specific considerations have also been given to the design and dimension ratio ranges to be used for these specimens.

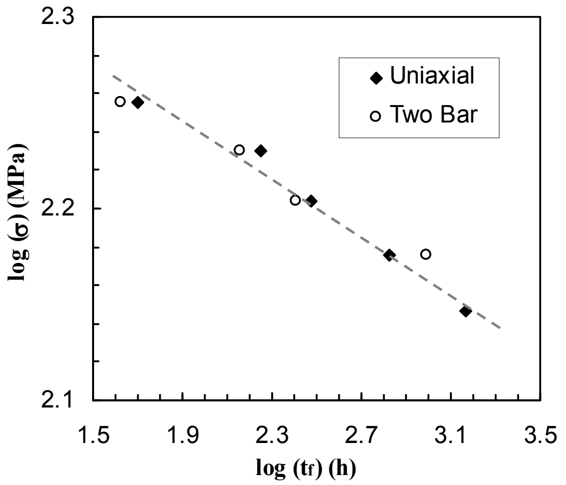

Fig. **10** Creep rupture data obtained from two bar and uniaxial specimens for a P91 steel at 600° C.

5. ASSESSMENT OF SERVICE-EXPOSED COMPONENTS USING IMPRESSION DATA

In order to realise its full value impression creep testing should be able to produce creep data equivalent to, or convertible to, those obtained by full-scale conventional creep testing. Impression creep testing should produce creep strain rates equivalent to those obtained in conventional tests under equivalent testing conditions. It has been shown (e.g. Fig. **8**) that test data of this quality can be produced. However, the method can also be used to rank the creep strength of the components sampled in–situ; this information can be of significant value to plant operators [**5,17**]. Since impression creep testing can reliably rank different sampled materials in the correct order of their conventional creep strength, the information can be used for prioritisation in inspection and/or repair programmes. Examples of such ranking exercises are given in the following sections.

5.1 Background

Coal-fired power plants constructed in the 1960s and 1970s in the UK utilised the low alloy steel ½CrMoV for high temperature steam lines. All these pipework systems have operated well beyond their original design lives and the risk of failure in the now aged material has to be addressed. A number of on-site techniques are currently being applied to provide estimates of vulnerability to cracking in service and to guide inspection programmes.

A key element in the process of justifying the continued operation of high temperature components is an estimate of the current creep strength. Acquiring creep data by conventional testing entails the removal from service of substantial amounts of material and usually necessitates a weld repair or refurbishment exercise with associated costs. The use of small scale sampling and testing techniques, which do not require a weld repair, provides an attractive alternative.

5.2 Creep Data Required in Life Assessment of Service-Aged Materials

Creep data may be required for the assessment of a specific component such as a header or steam chest, or for the assessment of a group of components such as the individual pipe sections making up a steam line. In the latter case, the aim may be to identify the weakest parts present in order to prioritise them for subsequent non destructive testing (NDT) programmes. This is particularly important where large numbers are present and it is not feasible to carry out NDT on the entire population.

For example, the main steam pipework system between the boiler outlet and the turbine inlet on a 500MW coal-fired unit in the UK will typically comprise four steam lines with a total of approximately one hundred individual pipe sections, each separated from its neighbours by circumferential butt welds. Cracking has occurred on welds for many years and inspection programmes are now well established. In contrast little such experience is available for the sections of parent material. The inspection of parent material items is therefore potentially a more random exercise. Small scale sampling surveys can contribute to a management strategy by providing information about the variation in parent material creep strength present, reducing the randomness of the selection process.

5.3 Materials and Scoop Samples

While all high temperature materials operating in the creep range are potential candidates for small scale sampling and impression creep testing, most attention to date has focused on the older steel ½CrMoV and the more recently utilised steel 9Cr grade 91.

½CrMoV (BS3604 Grade 660) was widely used on the older coal-fired and oil-fired power stations currently operating in the UK. In the case of the coal-fired stations the plant has operated for well in excess of the original design life and long term creep failure of this material is now a structural integrity concern.

Modified 9Cr or grade 91 (ASTM A335 P91 or A182 F91) is a more modern steel, which first entered service in the UK in the late 1980s in the form of retrofit secondary superheater outlet headers, replacing 2¼Cr1Mo components suffering from ligament cracking. Although the new headers have only been in service for approximately half their design life they have already suffered a higher than expected incidence of weld cracking. As discussed below in Section 5.4.1, small scale sampling and impression creep testing of parent material has found a role in indirectly identifying the sections most vulnerable to weld cracking. Fig. **11**(a) illustrates the device being used on a pipework system [**18**]. A typical scoop sample is shown in Fig. **11**(b).

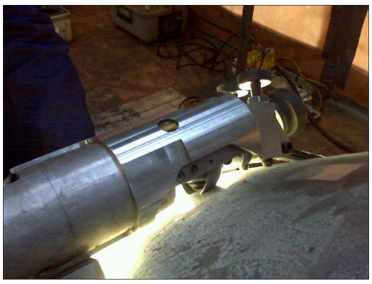

Fig. **11**(a) Scoop sampling in progress.

Fig. **11**(b) A typical scoop sample.

5.4 Case Studies

5.4.1 Application to Retrofit Grade 91 Headers

In the aftermath of several premature (Type IV) failures of welds in grade 91 components in the 1990s, RWE npower carried out a survey of its grade 91 headers to identify any that might also have been vulnerable to early failure. Attention focused on two headers (Fig. **12**) at one station leading to in-situ small-scale sampling exercise. Small scale specimens were then creep tested using both impression creep and small punch techniques. In a parallel exercise a weak grade 91 bar section, acquired from a header manufacturer, was used as a reference material. This was creep tested using both small scale and conventional testing.

It was established that the header and reference materials were similar in terms of creep strength. This is illustrated in Fig. **13** where the impression creep strain rates obtained for the samples taken from one of the suspect headers are ranked against the strain rate obtained for the reference material. It can be seen that the creep strength of the header samples is similar to, or weaker than, the reference material. Also shown are the results from a prematurely failed endplate and two other samples taken from plant items with no known problems.

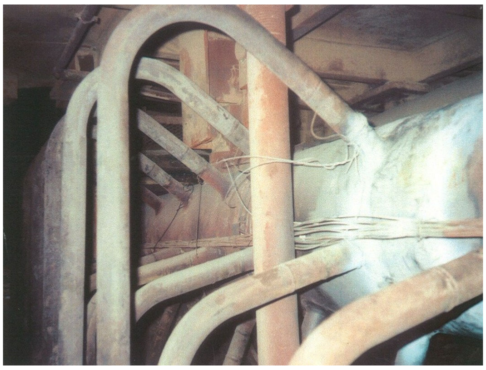

Fig. **12** Modified 9Cr header.

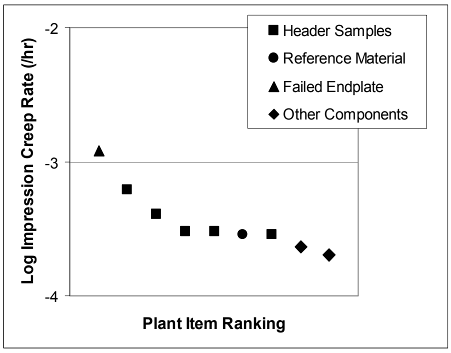

Fig. **13** Impression creep strain rates obtained from samples from the suspect header compared to a sample from a weak failed endplate and samples from other components.

The reference material was subsequently welded to provide cross-weld Type IV data and, as a direct consequence of the results obtained, early inspection of the headers was recommended. One of the headers was found to have extensive early Type IV cracking with the other being found cracked a few years later. In these cases, the use of small-scale testing enabled the damage to be caught at an early stage, avoiding costly failure in service and associated unplanned outage time. This example has been published as a case study [**19**].

5.4.2 Application to Aged CrMoV Steam Pipework

Small-scale sampling and impression creep testing is also being used by RWE npower as part of its methodology for managing these aged pipework systems. Those pipework components shown to have the weakest creep strength can be selected for additional monitoring within the broader inspection programme. The aim is again to increase the probability of identifying damage at an early stage. Fig. **14** shows a ranking plot for ½CrMoV, similar in form to Fig. **13**, but with significantly more tested samples. The dotted line intersects a sample which parallel conventional uniaxial testing has shown possesses a strength equivalent to the lower bound (mean-20%) ISO value for this material in the as-received condition. In principle all materials sampled lying to the right of this line are currently stronger than this minimum value, and can be regarded as presenting no particular concern in terms of creep strength.

Attention can therefore focus on the materials to the left of the line. Further information on this is published elsewhere [**18**].

5.4.3 Placing an Individual Material within a Creep Strength Scatter Band

Creep strength decreases with operation at high temperature and impression creep strain rates increase as operating hours increase. Figs. **13** and **14** both compare samples in terms of their current strengths at the time of sampling. While this may be useful for investigating in-service plant components of broadly similar age, it may be less suitable for comparing components of significantly different plant age, or indeed samples obtained from the same system or component at different stages of life. In these cases it may be more appropriate to use a correction factor to make comparisons on the basis of a common operating age.

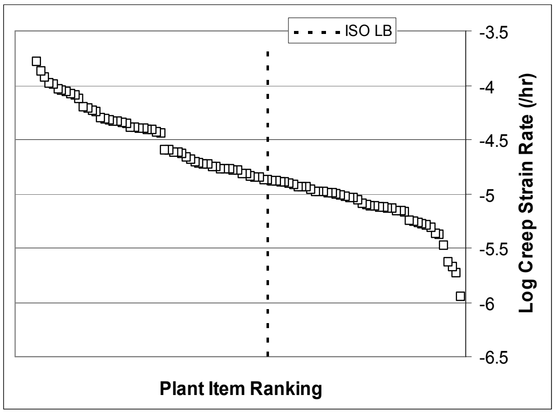

Fig. **14** Impression creep strength ranking plot for ½CrMoV.

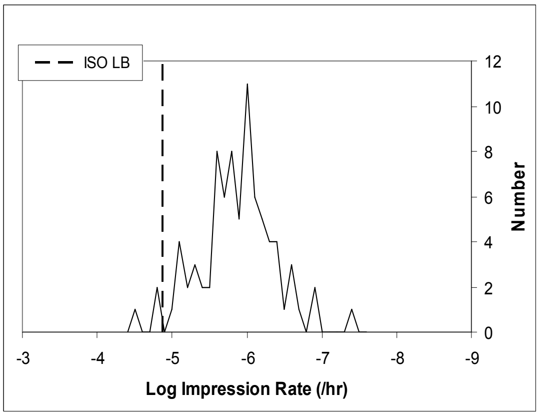

Fig. **15** Histogram showing the ½CrMoV data (in Fig. **14**), corrected for operating hours at the time of sampling to reflect strength at the start of life.

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. In Fig. **15** the ex-service ½CrMoV data have been converted to the strain rates which would have been obtained if the materials had been tested in their as-received condition prior to entering service. The impression strain rate corresponding to lower bound ISO for this material (which does not change) now lies near the bottom of the distribution, as might be expected. The usefulness of such a plot is that any other sample or set of samples, similarly corrected for operating hours at the time of sampling, can be placed in the scatter band.

6. DISCUSSION AND FUTURE WORK

It has been shown that all of the small specimen test types described in this paper are capable of providing reliable creep data. In the case of two of the methods (SPT and ICT) a great deal of test data and test experience exists and there is growing confidence in the use of such methods for practical proposes. The SRT method is relatively new and hence less data is available, but the results of the testing of a P91 steel (Fig. **9**) are very encouraging. The advantage of these types of test is a substantial reduction in the complexity of the equivalent conventional testing.

No use has yet been made of detailed small specimen creep data in the life assessment of specific components. Ranking tests to prioritise NDT however have been, and continue to be, used, e.g. [**17**]. In one case a grade 91 header was sampled to provide impression creep data for comparison with that of a cast known to have poor parent and Type IV creep strength. The results indicated that the casts present in the header were vulnerable to early Type IV cracking, which led to programmes of inspection at subsequent planned outages. Type IV cracking was eventually detected at an early stage allowing timely remedial action to be taken [**17**]. Ranking tests are also currently being increasingly carried out on aged ½CrMoV steam pipe. The aim is again to identify the most vulnerable parts of the system in order to prioritise NDT during planned outages. A broader goal in this case however 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.

Standardization of the testing methods is required in order for small specimen creep test techniques to be used more widely and to produce consistent data from difference laboratories at relatively low costs. Purpose-designed or modified test machines, with sufficient accuracy of load/temperature control and displacement measurement, are required for data production in an economical manner. Standardization will involve obtaining agreement on a number of essential issues, such as the basic requirements of test rigs, specimen dimensions, sampling and specimen preparation, temperature and loading control, and displacement measurement etc. In this respect, collaboration between academic institutions, industrial organizations and standard agencies would be ideal. A good example is the work of a "Code of Practice" for the small punch test method by CEN [**14**].

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